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THE INLAND TELEGRAPH SERVICE: THE INTRODUCTION OF MODERN MACHINERY AND METHODS.

By R. P. SMITH, Associate Member.

[*Paper first received* 28*th July*, 1931, *and in final form* 31*st May*, 1932; *read before* THE INSTITUTION 17*th November*, *before the* MERSEY AND NORTH WALES (LIVERPOOL) CENTRE 21*st November*, *before the* SOUTH MIDLAND CENTRE 5*th December*, *and before the* NORTH-WESTERN CENTRE 13*th December*, 1932, *also before the* NORTH MIDLAND CENTRE 10*th January*, 1933.]

SUMMARY.

Measures are being taken to modernize, popularize, and speed up the Inland Telegraph Service. Instruments and machinery new to the Service have been introduced with unprecedented rapidity. Teleprinters, typewriters, copper-oxide rectifiers, rotary convertors, thermionic valves, voice-frequency signalling, and band conveyors, are the main features of the reorganized system. Each of these items receives notice in the paper. Panel-mounted apparatus is a novel departure that has created considerable interest among telegraph engineers. In the circumstances it may be some time before technical literature giving a comprehensive account of the methods employed is available; the paper, therefore, describes the standard equipment in detail. A new class of technical officers for testing and maintenance duties has been created; the personnel is chosen from the general body of telegraph operators and receives training in an engineering school.

A telegraph exchange service, "The Telex," has been made available to subscribers to the telephone service, for whom the necessary apparatus is installed on rental terms. The renters are able to transmit and receive printed communications in addition to the usual telephone facilities. They may also transmit messages to the Post Office, creating a new class of traffic designated "Printergrams." We have telegrams, phonograms, and now printergrams. The supply of underground conductors is now more than adequate for the requirements of the public services, and channels of communication are offered to the public, on rental terms, for the purpose of private-wire circuits. The ascertained results of the reorganization, still far from complete, are in the direction of increased stability and accuracy. In addition, recent figures show an improvement in the financial position. In another direction there is evidence that the changes have not been entirely unfruitful as regards increased comfort and convenience of the army of workers who staff the telegraph instrument rooms of this country.

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INTRODUCTION.

During recent years the telegraph service of Great Britain has been the subject of prolonged and exhaustive study, with a view to making it more attractive to the public, more efficient as a means of communication, and less costly as regards the loss of State revenue. Following the report of a Committee appointed to examine the conditions of the Inland Telegraph Service in 1927, a Commission of Inquiry visited the United States of America during the autumn of 1928. The Commission made a considerable number of recommendations affecting all departments of telegraph administration; these recommendations are shown in Appendix 1. The first three Sections, (*a*) Apparatus, (*b*) Lay-out, and (*c*) Maintenance, are of particular interest to electrical engineers. It was decided to carry out experimentally certain of the principles laid down by the Commission, and the telegraph instrument room at Leeds was remodelled in accordance with the recommendations during the autumn of 1930. The experiment attracted a great deal of attention, and Leeds became a pilgrim centre. Telegraph officials from all parts of the country and, indeed, from other countries, came to consider and criticize the system and working conditions. The general impression is summarized in the following authoritative opinion published in a Service journal. "The arrangements at Leeds provide working conditions of a standard that has never yet been attained in the British telegraph service." A big programme of development on the same lines at other offices has been undertaken and, eventually, all the larger telegraph instrument rooms in this country will be dealt with. Apparatus familiar to past generations of telegraph engineers will be displaced in favour of panel-mounted units resembling more closely the apparatus in telephone and wireless stations.

It is the purpose of this paper to indicate certain of the problems associated with the telegraph service, and to describe the machinery and methods that have been introduced.

Importance of the Telegraph Service.

Despite the welcome growth of the telephone habit, the proportion of telephone subscribers to the total population is still small. The number of telephone stations in use on the Post Office system now exceeds 2 millions, whilst the estimated population of Great Britain is 45 millions. It is clear, therefore, that the majority of the public, in times of business emergency or sudden distress, rely upon the telegraph service for effecting their communications. It provides a uniform and expeditious service within reach of all classes, and is accessible to all parts of the country. For communicating with a number of persons simultaneously, or advising prices and market changes to a large clientele, the telegraph service is the most convenient method; it is also the cheapest means of rapid communication over long distances. Its value to the public at a time of local or national emergency must not be overlooked. Temporary interruption of a main telephone cable has the immediate result of a flood of telegrams from people in the area affected who find no outlet for quick communication on the telephone system. Perhaps the most striking instance of the ability of the telegraph service to meet the strain of an emergency occurred immediately prior to the railway strike in 1919. On the 29th September of that year the Central Telegraph Office dealt with a record total of 355 353 telegrams. Similar conditions, over a longer period, obtained upon the outbreak of war in 1914. Such circumstances as these justify the maintenance of a telegraph service with equipment in excess of the normal requirement. It provides a second line of defence against dangerous delay and chaos at any time of national upheaval.

Telegraph traffic is diminishing, it is true, yet in the year 1931 the Post Office dealt with a total of 37·6 million inland telegrams and maintained 6 500 sets of signalling apparatus for the public service.

Telegraph Offices.

There are 11 400 telegraph offices in Great Britain and Northern Ireland. The number, of course, varies slightly from time to time, owing to changes in the density of population. The instrument room may be a small cubicle on the premises of a sub-postmaster, or an office at a railway station, where a few single-needle and double-plate sounder instruments—relics of a past era—still survive, a floor in an important head post-office, or a block of buildings, such as the Central Telegraph Office, where the total indoor staff of all grades numbers 3 860, and 700 circuits are installed. Some idea of the size of this office may be gathered from Fig. 1 (Plate 1, facing page 204), which shows a small portion of one of the five floors.

Classification.

The method of linking up the centres of population for telegraph purposes is to classify offices under the four following descriptions:—

(1) Minor offices. These offices, apart from a few exceptional cases, send and receive their own traffic only.

(2) Group centres. These offices are the general collecting and distributing centres for the minor offices grouped under them.

(3) Area centres. These offices collect and distribute traffic to and from offices within their area.

(4) Zone centres. These offices form the principal transmitting centres between offices within their own zone and all other zones.

Incidence of Traffic Load.

In common with telephone traffic, telegraph traffic fluctuates considerably according to the hour of the day, the day of the week, and, in most cases, the season of the year. The following figures serve to illustrate this ebb and flow of the traffic load. In the Central Telegraph Office, London, the average number of inland telegraph transactions during the busy season (June) is 161 518 daily. The number during the slack season (January) is 114 000, a drop of approximately 28 per cent. The average load during the peak hour (11 a.m. to noon) in the former case is 21 368, and the average load during the hours 8 a.m. to 8 p.m. is 154 508. On one occasion 89 000 telegrams were tendered in one batch at this office. Such an occurrence, of course, completely upsets the law of averages and staff provision. At popular seaside resorts the volume of traffic during the season is very great compared with the trickle during the "off" season. At Douglas (Isle of Man), for example, the daily average number of telegrams at the height of the season is 1 271, whilst in the winter the daily average is 346. Since it is imperative that delay at the forwarding point should be kept at a minimum, it is necessary to provide equipment capable of dealing with the maximum load; a sufficient number of terminal apparatus sets must be installed, and reserve lines maintained, to prevent congestion during periods of pressure.

While it is practicable to transfer staff from office to office to deal with seasonal pressure, it is not economical, apart from certain exceptional cases, to transport apparatus to offices for short periods. It will be realized, therefore, that a great deal of telegraph equipment is not employed to its full capacity and that, for general purposes, flexibility of apparatus in relation to fluctuations of traffic is a matter of great importance.

Contrasts Between a Telephone Exchange and a Telegraph Instrument Room.

A non-technical visitor to a telegraph instrument room is impressed by the amount and variety of apparatus at the operating positions, as compared with the switchboard equipment in a telephone exchange. In the latter case the operator has everything compact, mounted on a panel and a shelf; but in the former the operator is dwarfed by a formidable assembly of galvanometers, relays, boxes, lamps, and switches, spread about the operating positions. The explanation is, partly, that telephone apparatus does not require frequent adjustment and can be placed in a position remote from the operator, whereas the terminal apparatus of a telegraph line, usually required to work duplex, requires frequent adjustment to follow the changing line conditions.

As the proportion of underground to aerial conductors increases, the chief objections to remote control will be

overcome, since, apart from slight seasonal changes in the ohmic value, the artificial-line values for underground circuits remain constant. It is becoming possible, therefore, to introduce the telephone practice of rack-mounting auxiliary apparatus, and, where teleprinters are introduced, working on line circuits of the latest type, the removal of all apparatus, other than operating units, from the instrument table is essential for the following reasons:—

(1) The number of apparatus units required cannot be accommodated on the instrument table.
(2) The receiving operator's position is overcrowded.
(3) Vibration of the instrument table, set up by the teleprinter motors, adversely affects finely adjusted apparatus.

Methods of Obtaining a Telegraph Circuit.

Line Provision.

Make-up of circuits.—In regard to the transmission of signals, the lines carrying the traffic between telegraph offices under existing circumstances must be made up by employing conductors of different types and degrees of efficiency. Formerly, aerial lines were in general use for telegraph circuits, but as the network of cables spreads, conversions from overhead to underground conductors are continually being made. In March 1921 the total working telegraph wire mileage was made up of 148 977 miles of aerial line and 116 203 miles of underground line, i.e. 44 per cent was underground. In March 1930 the position had changed to 97 282 miles of aerial line and 203 144 miles of underground line, i.e. 67 per cent was underground. The progress of conversion from overhead to underground conductors during the period March 1922 to March 1931 is shown in Fig. 2. Coincident with the introduction of underground conductors, a demand for additional terminal equipment with increased efficiency arises. Instruments designed for use with the currents normal to aerial circuits are not so suitable for working with small currents on cable circuits, where greater signal distortion is encountered.

The outlook, so far as line provision for the telegraph service is concerned, has been profoundly affected as a consequence of the by-product channels of the modern main underground telephone cables. Double-phantom circuits in multiple twin cables, phantom circuits in star-quad cables, and a considerable number of spare physical circuits, are available for use for telegraph purposes if adequate precautions are taken to prevent the telegraph currents from disturbing telephonic communication. The introduction of such circuits results in savings in respect of line charges, since the existing telephone line plant is utilized without loss of efficiency and with very little alteration at the telephone repeater stations. The Post Office Research Station has devoted considerable attention to the question of interference, and has developed an arrangement of terminal apparatus which eliminates disturbance, allowing telegraph signals to be superposed on telephone circuits without materially degrading telephone transmission.

The various methods of making up telegraph circuits are shown in Fig. 3.

Type 1 represents a telegraph circuit on an aerial conductor, or an underground, single, screened conductor.

Type 2 represents a telegraph circuit on an underground pair, the power being derived from an earthed battery. This circuit is usually formed by signalling on the A wire and connecting each end of the B wire to earth.

Type 3 represents a telegraph metallic-loop circuit; a separate battery is required at each office for this circuit.

Type 4 represents a telegraph metallic-loop circuit, with an earthed telegraph circuit superposed.

Type 5 represents two telegraph metallic-loop circuits, with a telegraph metallic-loop circuit superposed.

Type 6 represents a telegraph metallic-loop circuit in a multiple twin cable, with an earthed telegraph circuit superposed. The second pair is earthed, both A and B wires, to form a screen for the superposed circuit.

Type 7 represents a telegraph circuit, worked with earthed batteries, using two underground loops. The

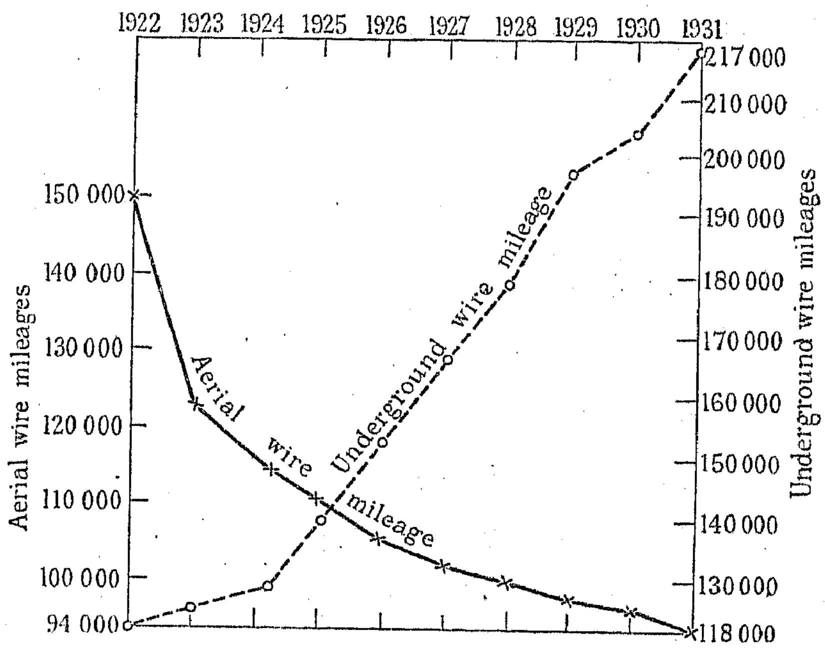

Fig. 2.—Telegraph wire mileage, aerial and underground.

communication in this and Types 8 and 9 is unidirectional, one loop being used exclusively for signalling by each office.

Type 8 represents 4 pairs in a multiple twin cable, forming 4 telephone circuits, with 2 phantom telephone circuits superposed on the 4 pairs, and with a telegraph channel working as a loop on the double-phantom circuit.

Type 9 represents 4 pairs in a cable of the star-quad pattern, forming 4 telephone circuits with two telegraph channels superposed, working as loops.

There are also a small number of 4-wire repeater circuits in use for voice-frequency installations.

Circuits employing the line conditions shown under Types 8 and 9 are new to the telegraph service. The first circuit of this character was set up experimentally between London and Glasgow in 1929. The route mileage is 447 miles, constituting a record for an underground circuit working without a telegraph repeater. Although good working conditions were obtained, the margin of the circuit was somewhat narrow, and experiments were made with various types of loading for the double-phantom telegraph channel at the telephone

repeater stations. The result was very satisfactory after the correct values of the inductances had been determined, and the circuit is in constant use for traffic purposes.

A considerable number of circuits of this class are known as 2-loop simplex working, is well adapted to present requirements. The two halves of the circuit are entirely independent, a duplex balance is not required, and local adjustments are of a simple character. The

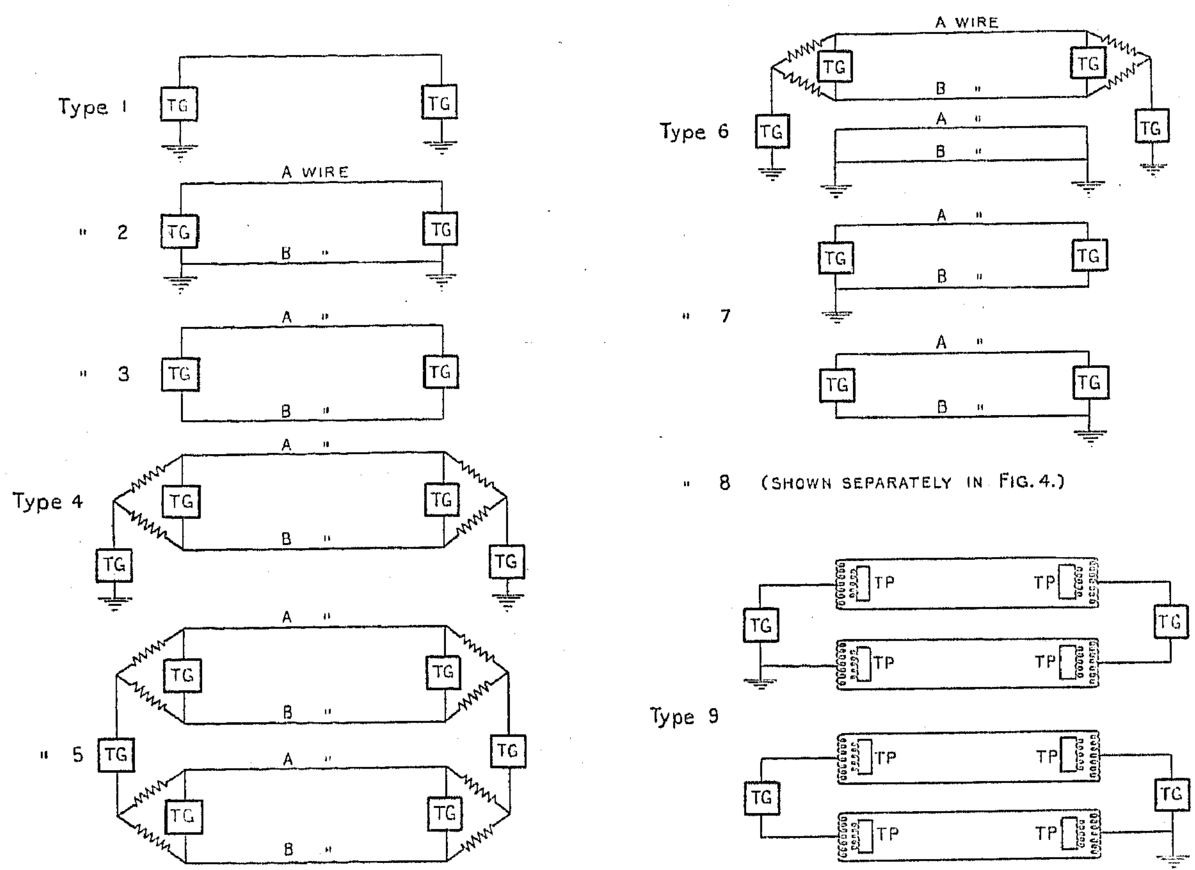

FIG. 3.—Methods of obtaining a telegraph circuit.
TG = telegraph apparatus. TP = telephone apparatus.

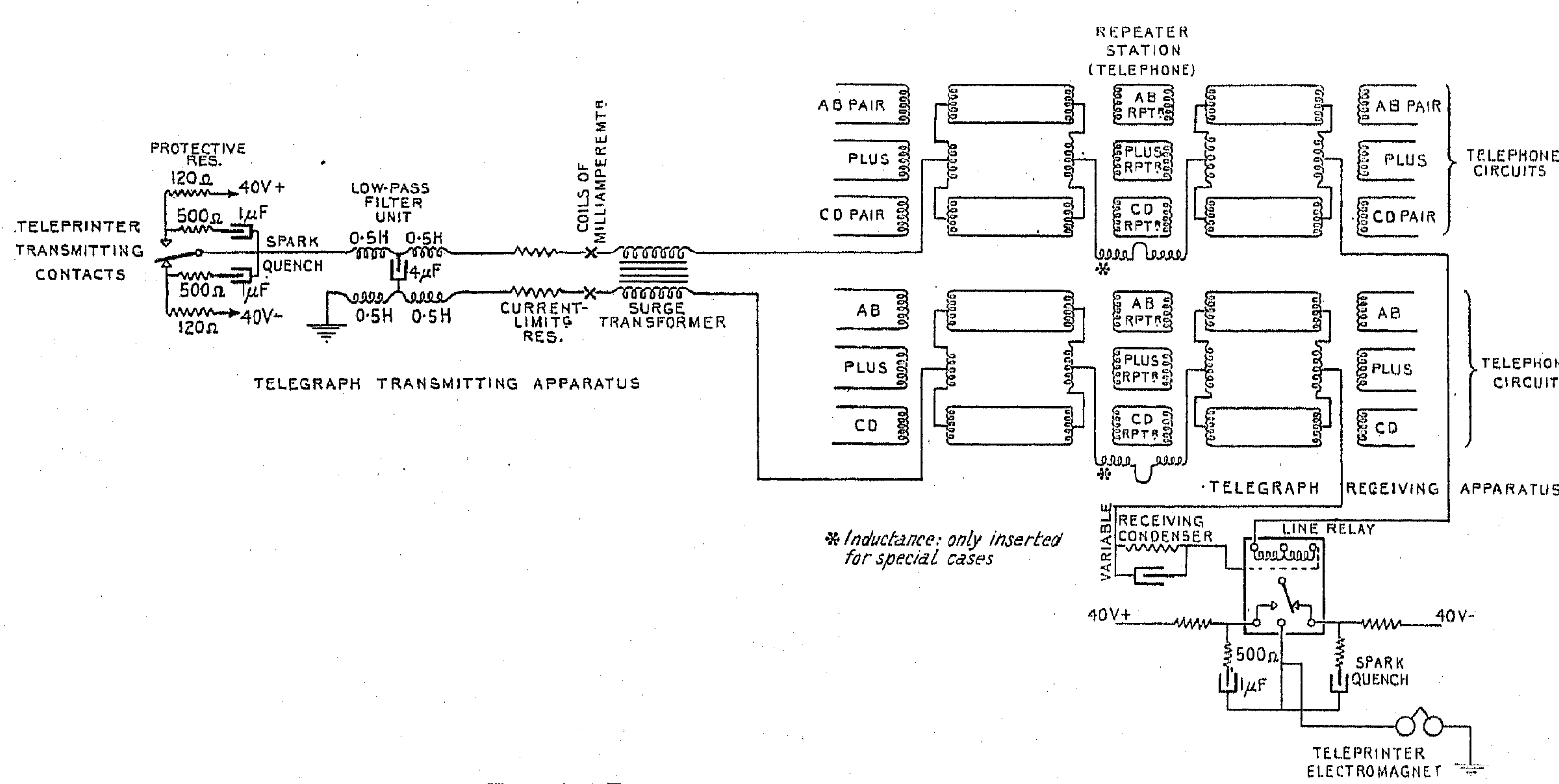

FIG. 4.—Double-phantom circuit, sending channel.

being introduced. Fig. 4 shows, in addition to terminal units, the method of arranging the lines. It will be observed that the channel is unidirectional. In practice, a second channel with sending and receiving conditions transposed at the telegraph offices is provided, thus giving the equivalent of a duplex circuit. The method, values shown in Fig. 4 for the filter and spark-quench units are not critical. Slightly different values are in use in some cases. Usually the line relay is of the vibrating type. The functions of the apparatus are indicated in the figure, so that further explanation is unnecessary.

Telegraph Systems.

Various systems of telegraphy have, each in turn, dominated the telegraph instrument room since the transfer of the telegraphs to the State in 1870.

The growing volume of traffic, culminating in a load of 94 million telegrams in 1920, could only be dealt with by increasing the speed of transmission over the limited number of lines available. The Morse sounder circuit, having a working speed of about 25 w.p.m. (words per minute), developed into the quadruplex system, which doubled the output. Then followed the Wheatstone system, allowing a line transmission speed of 300 to 400 w.p.m. Multiplex systems next came to the front, giving, in the case of a standard quadruple Baudot installation, a maximum output of 120 printed words per minute in each direction with manual transmission, or 140 w.p.m. with automatic transmission. Each succeeding system raised the expenditure upon terminal apparatus, but, except in the case of short circuits, the additional cost of providing and maintaining

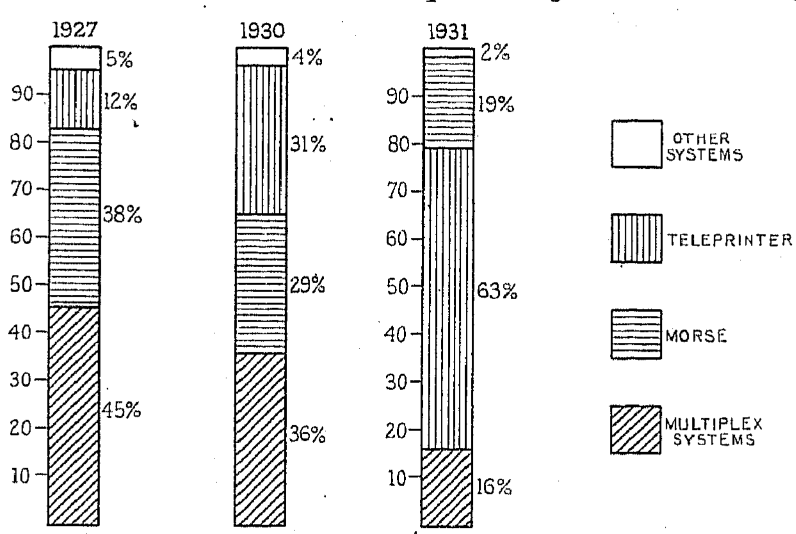

FIG. 5.—Traffic load of telegraph systems in use.

such apparatus was less than the cost of construction involved in providing additional lines.

The telegraph service is now passing through another transition period, the policy of the Post Office being to remodel the service on a type-keyboard machine basis. The first steps in this direction had already been taken, prior to the report of the Commission of Inquiry. As a result of the adoption of Recommendation 1 (*a*) (1) to (8), however, the programme was accelerated. Multiplex installations represented by Baudot, Western Electric, and Murray systems have been replaced on all inland circuits by start-stop instruments, known as teleprinters. It is also the intention to abolish Morse and Wheatstone working, so far as ordinary signalling purposes are concerned. The rapid progress made in this direction since 1927 is indicated by the chart shown in Fig. 5. It will be observed that, in slightly over $3\frac{1}{2}$ years, the teleprinter has absorbed approximately 50 per cent of the traffic formerly carried by multiplex and Morse systems. More recent figures would show a further heavy transfer of traffic in the same direction, since, with a few exceptions, all inland circuits having 150 or more telegraph transactions per day at any period of the year are scheduled for conversion to teleprinter working. The number of circuits so equipped is in the neighbourhood of 650. In large centres, where multiplex has been the principal system for over a decade, the traffic, manipulative, and engineering staffs have been called upon to master the intricacies and eccentricities of new machinery in a comparatively short space of time and to effect a change of system without interruption or degradation of the public service. It is satisfactory to be able to state that, during the transition period, there has been progressive gain as regards one of the vital requirements of the telegraph service, namely circuit stability. The stoppages of teleprinter circuits, excluding those due to line failures, now average 8 minutes per week; it is safe to say that such a degree of reliability has never before been experienced in the telegraph service.

THE TELEPRINTER.

The first teleprinters used by the Post Office were made in America; they were produced under the proprietary name of " Teletype " and were installed by the Post Office in 1922 on a circuit between two London offices. The instrument now in general use, a British machine known as Teleprinter No. 3A, was first used by the Post Office on a London–Colchester circuit in February 1928. Since then about 2 200 instruments have been introduced, either as working or reserve machines. Teleprinter working is a start-stop system of printing telegraph using a 5-unit code. The apparatus at each end of a line circuit is at rest unless actually transmitting or receiving signals, but a small electric motor runs continuously, driving several spindles by means of gear wheels. The operation of an electromagnet results in the engagement of a spindle for the period of one revolution, during which a train of mechanical movements is set in motion to print the character signalled. On the transmitting side, the depression of a key causes engagement with another spindle for the period of one revolution, during which a sequence of currents is transmitted. The first current starts the distant receiving train, the five unit currents following determine the character to be printed, and the last current disengages the mechanical movement. The maximum operating speed of the machine is 61 w.p.m.; up to this speed the keyboard is free and the operating speed is dependent upon the ability of the operator. The transmission speed, however, is constant at 66 w.p.m. (25 cycles per sec.), irrespective of the operating speed. The speed of the motor is controlled by a governor of the centrifugal type and is not critical, since unison of speeds of the two machines on a circuit is confined to the period of one revolution. It is found in practice that perfect working is compatible with a difference of 2 per cent between the speeds of the two teleprinter motors. A detailed description of the machine will not be attempted since it has been fully described in various technical journals. Compared with other systems of telegraphy, the line transmission speed of the teleprinter is low, but notwithstanding this the average output per operator is higher than that achieved over Wheatstone or multiplex circuits.

The basis on which staff is provided for telegraph traffic disposed of over various types of circuits is shown in Fig. 6.

Since the charges in respect of operating are relatively

high as compared with other charges, the economy achieved by increased operator output is important. The teleprinter has this advantage also, that the highly skilled operating staff necessary to maintain efficient working on other systems is not essential. Touch-typing is the principal qualification for an operator on the dispatching side, whilst the received message is printed on a paper ribbon, or, with the latest column-printing machine, on a message form direct.

Although the teleprinter has a great deal in its favour when viewed from the standpoint of the operating room, its general introduction has given rise to problems in relation to:—

(1) Handling and accommodation.
(2) Power supply for the motors.
(3) Power supply for the line and local circuits.
(4) Maintenance of machines.
(5) Replacement of machine parts.

(1) *Handling and Accommodation.*

The Morse, Wheatstone, and multiplex systems have separate units for sending and receiving, whereas the

SYSTEM	UNIT TELEGRAMS PER OPERATOR-HOUR
MORSE	36
MULTIPLEX	48
TELEPRINTER	62
WHEATSTONE (STICK PUNCH^{G})	33 EQUIVALENT OF 11 PAGES OF PRESS
WHEATSTONE (KEYBOARD PERFORATORS)	54 EQUIVALENT OF 18 PAGES OF PRESS

FIG. 6.—Basis of staff provision for telegraph traffic.

teleprinter is a combined instrument having transmitting, receiving, and motor units assembled on a metal base fitted into a baseplate provided with carrying handles. This combination has certain advantages, but the machine is fairly heavy and bulky in comparison with other telegraph instruments. The Morse key and sounder together weigh 10 lb. and cover 90 sq. in. of the instrument table, while the figures for the Baudot key and receiver are $35\frac{3}{4}$ lb. and 145 sq. in., and for the teleprinter 80 lb. and 292 sq. in.

A teleprinter, in conjunction with the necessary line terminal apparatus, switches for motor supply, etc., occupies so much of the 5 ft. 6 in. allotted to each circuit on the instrument table, that the receiving operator is cramped for space; adjustments of the duplex balance are difficult to make on account of the spread of the apparatus. The weight of the machine and the necessity for preserving its balance whilst being carried, renders its transport in the instrument room somewhat troublesome. At the larger offices a trolley has been provided which is wheeled to the instrument table to enable the teleprinter to be shifted with a minimum of lifting power. The replacement of faulty machines, together with a certain amount of movement on the table to meet operating conditions, played havoc with the mahogany surface of the instrument tables, due to the metal parts on the underside of the baseplate cutting into the wood, or the cork carpet of the latest type of table. To prevent this damage, experiments have been made with turn-tables of various types. The results, however, were not sufficiently satisfactory to warrant their general introduction. Strips of thick felt secured to the underside of the baseplate or, alternatively, felt pads at each teleprinter position, are now being provided.

(2) *Teleprinter Motor Supply.*

A $\frac{1}{12}$-h.p. shunt-wound motor is employed to drive the teleprinter mechanism; wherever possible the local electric light supply is utilized for the drive. Should the supply voltage be unsuitable, in large offices alternative provision is available from a 120-volt universal battery installation. At small offices, however, the battery in use for displaced Morse circuits is quite inadequate for the motor drive; consequently the electric light supply must necessarily be employed. The lack of a standardized system of power supply has proved vexatious since, to meet the various a.c. and d.c. supply systems existing, suitable motors are required. This has created a further complication. Teleprinters with different motor units are not interchangeable, and a stock of each type must be held to provide for replacements. The a.c. motors have not given satisfactory service under instrument-room conditions and, in view of the circumstances already mentioned, it has been decided to standardize a 110-volt or 220-volt d.c. motor for the service. Where the public supply is alternating current a rectifier is installed to convert to direct current. Westinghouse copper-oxide units have been introduced at small offices in considerable numbers. Two types are in use, one for offices where the supply is 100–120 volts and the other for 200–240-volt supplies. Tappings are led out from the primary windings to provide for adjustment. The first type has a rated output of 110 volts at 0·75 amp. (d.c. mean). These rectifiers occupy a space of 269 sq. in. and weigh 45 lb. each. They are accommodated in the instrument room, mounted either on a wall or, where a number are required, in tiers on a metal rack.

A serious difficulty arises where a public power supply is not available, a situation which exists in certain parts of the country. There have been cases involving the provision of secondary cells and a small petrol-driven generator for charging purposes, a somewhat expensive expedient.

(3) *Teleprinter Circuits. Line and Local Power Supply.*

The line current for telegraph circuits is usually in the neighbourhood of 15 mA; rather more is required for aerial circuits to allow for leakage, whereas for the 2-loop simplex circuits described the value is reduced by half, since two coils of the line relay are in the receiving circuit. The teleprinter is in the local circuit of the line relay, hence the line current is the same as for other systems of telegraphy. A multiplex installation is usually replaced by three teleprinters, involving the provision of three line circuits and increased battery plant in the same proportion. In the majority of cases, long-distance circuits working on underground loop conductors, requiring independent batteries of 100–120 volts, are concerned. This demand for additional

power has strained the battery-room accommodation to the utmost at most of the large offices.

In the case of Leeds, prior to the reorganization in May 1930, 22 loop batteries consisting of 1 170 cells were maintained. In February 1931, 29 loop batteries consisting of 1 710 cells were maintained and six additional loop batteries were required for which accommodation was not available. The difficulty at Leeds and other offices has been met by providing small rotary convertors or motor-generators. A teleprinter working double-current—the normal method—requires two batteries, positive and negative respectively. If the supply is 120 volts, rack accommodation 14 ft. 0 in. × 1 ft. 10 in. is required for the cells. In contrast to this, two rotary convertors to supply the positive and negative voltages occupy 3 ft. 3 in. × 1 ft. 10 in. of racking; 140 of these machines are now in use at the Central Telegraph Office. Their performance at this and other offices is generally satisfactory, although a certain amount of trouble was experienced with machines having separate generators for the two voltages.

Additional plant is also required for the local circuit of the teleprinter. The electromagnets of the receivers on a Baudot circuit are non-polarized; they are all served from one 40-volt battery on the marking side of the line relay. The teleprinter electromagnet is polarized and requires a positive and a negative battery for the local circuit of the line relay; 80 volts is normally in use. Thus a change of system involves six 80-volt batteries to replace one 40-volt battery. At all large offices a universal battery is installed. The increased demand therefore creates no difficulty, since the battery has a capacity in excess of all possible requirements. The small office involves additional provision. The Morse sounder is worked from four Leclanché cells which can be packed in a small box, so that when Morse is replaced by teleprinter there is need of additional battery accommodation and difficulty frequently arises.

The rectifier already referred to has been used in a small number of cases to provide all the power required for teleprinter circuits—motor, line, and local. The trials have, on the whole, been successful, and when the requirements are fully met it is probable that a widespread use of this method will be made. The need for development in this direction will be realized when it is mentioned that, for telegraph purposes, the Post Office maintains 51 500 primary cells and 47 500 secondary cells. The connections of a teleprinter set supplied from a rectifier are shown in Fig. 7.

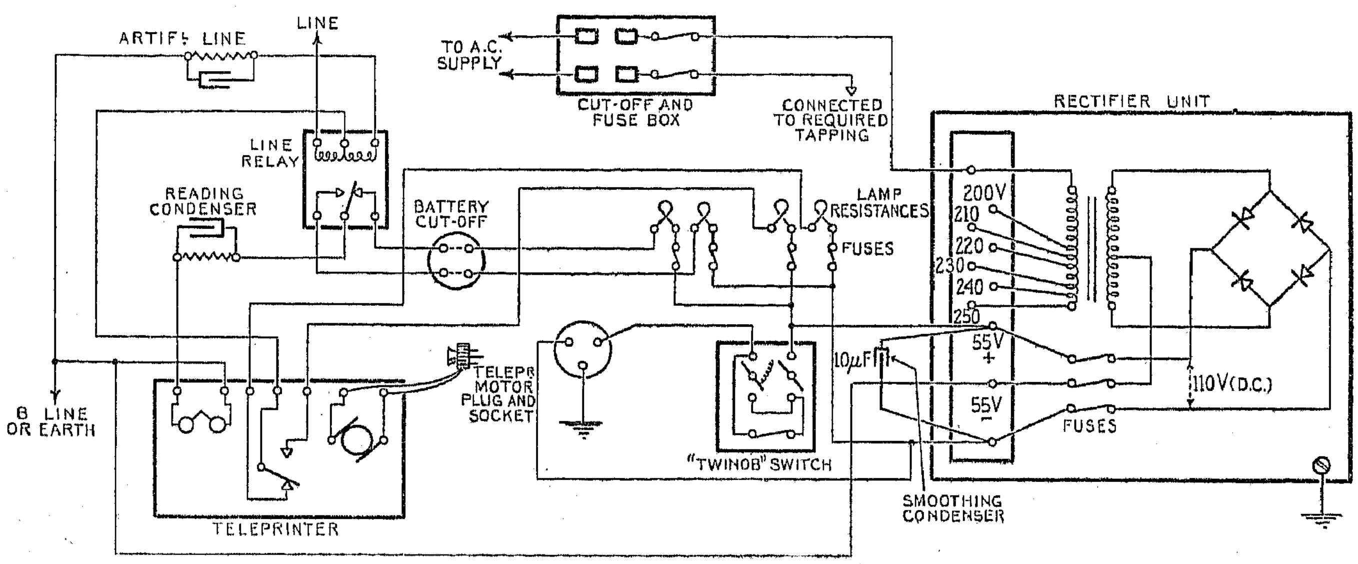

FIG. 7.—Teleprinter apparatus set with power obtained from a.c. mains.

(4) *Teleprinter Maintenance by Engineering Staff.*

At offices where Morse circuits only are installed very little engineering maintenance is required in the instrument room. Minor adjustments to keys, sounders, and relays are usually made by the operating staff, whilst instruments with serious faults are exchanged through the stores department. A high standard of maintenance service is required for teleprinters as, in addition to a knowledge of the electrical circuit, a considerable amount of mechanical skill is required. The maintenance officer must be able to decide whether trouble is due to motor speed variation, a faulty line, mechanical failure, or maladjustment of the transmitting contacts. At fairly large telegraph centres no difficulty arises, as sufficient work exists to employ engineering staff solely for instrument-room duties. At small offices, however, where only one or two machines are installed, the requisite experience is not usually available. The maintenance officer may be employed upon telephone exchange duties for seven-eighths of his time. In other instances the duties are outdoor, patrol, inspection, and repair. The service is safeguarded against serious interruption by the provision of spare machines, and where only one set is required a reserve position, fully wired, is installed. If a machine or piece of apparatus develops a fault the alternative position may be brought into use by operating a switch. To enable engineering grades who are employed upon teleprinter maintenance to gain experience, a training centre has been established at the Post Office Research Station, Dollis Hill, London. When conversion to teleprinter working at a small office has been decided upon, arrangements are made to release the local engineering officer for a fortnight's training. The course of instruction covers circuit arrangements, diagrams, electrical operations, mechanical movements, and working adjustments of the machine.

A machine withdrawn from service by the testing and maintenance staff is passed to the engineering staff for

attention. The repair work is, as far as possible, carried out locally. Machines beyond repair locally are dispatched to an overhaul centre in the engineering district, whilst repairs requiring special tool equipment are dealt with at the Holloway Factory, London. Under the new scheme teleprinters are subjected to a periodical overhaul. When a machine is due to be overhauled it is replaced from the overhaul-centre stock, dismantled, and thoroughly examined; all defective parts are replaced. Each teleprinter has an associated life history card which accompanies it, whether in service or under repair. A complete record of faults, repairs, and overhaul dates is made on the card in order that a fundamentally defective machine may be detected.

(5) *Teleprinter Maintenance by Traffic Staff.*

The adoption of recommendation 1 (*c*), (13) and (14),* involved the transfer of day-to-day maintenance of telegraph apparatus at certain offices to a " testing and maintenance staff " selected from the traffic staff and trained for the work. This staff is responsible for the daily cleaning, oiling, and adjusting of teleprinters and multiplex apparatus, also testing and repeater duties, minor repairs, and replacement of broken parts. The transfer has been taking place, gradually, during the present year. The new system depends for its success upon the keenness and ability of a staff of testing and maintenance officers chosen from the general body of telegraph operators.

For many years the Post Office has encouraged the study of technological subjects allied to telegraphy, by awarding additional remuneration to the holders of certificates issued by the City and Guilds of London Institute and the Engineer-in-Chief. Students obtained instruction in their own time and at their own expense. Until recently, the only technical instruction given during official hours was to a selected body of operators in training for dirigeur duties on multiplex installations. In future, new entrants to the telegraph service will receive training in " Elementary technical telegraphy, including minor adjustments of teleprinter apparatus " as part of their normal course of instruction. The rising generation of telegraphists should, therefore, be conversant with technical details of the machinery they handle and be able to make working adjustments.

During the early period of teleprinter development, a school was conducted in the Central Telegraph Office for selected supervising and maintenance officers from London and the provinces. They were given a course of lectures by engineering staff who specialized in start-stop machines. Over 500 officers, men and women, received tuition in this school, but a much wider scheme of technical training was required to meet the demand for fully qualified men and women arising from the new conditions. The need has been met by the establishment of a training centre equipped to cover a comprehensive syllabus of technical instruction. The school has accommodation for 30 students. It is situated in the Central Telegraph Office, London, and has a teaching staff of engineering officers. The students, who must hold the certificates already referred to, are admitted after a preliminary qualifying examination; they attend the school for 28 days, and undergo a final test before being certified for the testing and maintenance duties. The school has three sections: (1) a section equipped with teleprinters and apparatus sets of every description; (2) a section equipped with testing instruments, power plant, and a complete section of panel-mounted telegraph apparatus; (3) a section equipped with automatic Baudot apparatus, for terminal and intermediate stations. The syllabus of the course is shown in Appendix 2.

* See Appendix 1.

(6) *Replacement of Machine Parts.*

The teleprinter is a " Pandora's box " to the maintenance engineer; it has in all about 650 separate parts. A number of spare items, those most likely to be required, are supplied to each office with the machine, while other parts are supplied on application to the Stores Department. In order that a broken or defective part could be identified in the stores list and obtained with the least possible delay, the manufacturers' descriptions were brought into line with Post Office terminology. Each part was photographed, and the whole was catalogued in a technical instruction issued in 1931.

The Leeds Reorganization and Its Developments.

It would not be an exaggeration to say that the telegraph instrument room at this office has been revolutionized. Lay-out, machinery, furniture, lighting, decoration, everything down to the smallest detail, has been studied with a view to the provision of a service of maximum efficiency and a maximum degree of convenience for the operating staff.

The lay-out of the instrument room early in 1930, prior to the reorganization, provided accommodation for the following apparatus sets:—

- 6 Baudot installations providing 28 channels.
- 11 Morse duplex circuits.
- 1 Quadruplex set.
- 32 Morse circuits connected to a concentrator.
- 3 Creed receivers and 3 printers.
- 11 Wheatstone sets.

The principal use of the Creed and Wheatstone apparatus was to deal with traffic associated with the dissemination of news or provide outlets should an important multiplex circuit break down. The lay-out of the instrument room subsequent to the reorganization is shown in Fig. 8. The concentrator for Morse circuits, Creed apparatus, and Wheatstone circuits remained temporarily. The Baudot installations disappeared entirely, leaving 38 teleprinter circuits working and 4 reserve sets, also 27 circuits on the Morse concentrator. Perhaps the outstanding feature of the rearrangement is the segregation and rack-mounting of line terminal apparatus.

A space 32 ft. 6 in. × 18 ft. 0 in. was set apart for the accommodation of the segregated apparatus, providing sufficient room for the erection of 3 rows of bays having a maximum capacity of 72 circuits. Initially, rack accommodation was provided for 48 teleprinter duplex, and 5 Morse duplex circuits, the latter being in view of an anticipated interval before the conversion of all circuits to teleprinter working could be arranged, and during which provision for Morse working would be

required. The teleprinter programme made such rapid progress, however, that by the time the racks were installed, Morse working was not required. The rack-mounted apparatus is assembled on unit-type bays each measuring 6 ft. $\frac{3}{8}$ in. × 1 ft. $8\frac{1}{2}$ in. They consist of a frame of mild-steel channel 3 in. × $1\frac{1}{2}$ in. × $\frac{5}{16}$ in., fitted with a base of 6 in. × 6 in. × $\frac{1}{16}$ in. angle, mild steel, drilled $\frac{1}{2}$ in. clear to take Lewis bolts for floor fixing. Stays being undesirable from an æsthetic point of view, individual bays are drilled $\frac{3}{8}$ in. clear and bolted together to give the required degree of stability. Mounting-plates of $\frac{1}{4}$ in. cold-rolled mild steel are fastened to the frames by means of Whitworth hexagon-head set-screws. The plates are spaced, as required, to accommodate the various units employed.

Two rows of 17 bays each, and a section of six bays in the third row, were provided in the first instance. A small intermediate distribution frame, and a relay test bay having a concentrator panel, are aligned with the first row. At one end of the first two rows a testing table placed at right angles to the bays is provided.

Each section of bays comprises 4 apparatus bays, a test bay, and a power bay. A test bay is placed in the middle of four apparatus bays and associated with a power bay on the right-hand side of the group. This arrangement is seen in Fig. 9 (Plate 1). At the extreme left of the row of racks is the intermediate distribution frame. The sequence of bays looking to the right of the distribution frame is as follows:—Two apparatus bays, a test bay, two apparatus bays, and a power bay. Only two power bays are required for three sections, so that the row of bays in Fig. 9 comprises three complete sections. The concentrator and relay test-panel are placed at the extreme right of the row.

Three tables carrying apparatus of the old type are seen in front of the racks. After a short period these instruments were withdrawn and the space was devoted to a new form of panel to be described later.

Development of the Leeds Model.

The general principles of segregation and rack-mounting having proved successful under working conditions, the reorganization, on similar lines, of all large instrument rooms is anticipated. The ideal method of housing the racks would be to install them in a position remote from the instrument room, where space is less valuable. There was some hesitation, however, in adopting this method, although a step in this direction has recently been taken. The racks for the voice-frequency equipment of a number of circuits radiating from London are installed in the basement of the Central Telegraph Office, whilst the working positions are on the third floor.

The Leeds equipment required a floor space of 10 ft. 3 in. by 1 ft. $5\frac{1}{2}$ in. for each section of racks, and the possibility of reducing this space for further installations was considered. Bays extending 9 ft. 0 in. above the floor-level would enable an increased number of circuits to be associated with each test bay, but there would be certain objections from the point of view of the commercial staff:—

(1) It is considered that 8 circuits is the maximum number that can safely be grouped with one set of testing apparatus. Should two or more of the 8 circuits require attention simultaneously, delay would arise, and with a larger group of circuits the liability to overlap would increase.

(2) The testing officer requires a space of about 4 ft. 6 in. in front of the test bay. A test teleprinter is wheeled to the position on a trolley when it is required, and the officer is seated when working to a station.

(3) The tall equipment would, in certain offices, cast shadows on the operating field.

These considerations, therefore, defined the limits for new construction. New apparatus units were designed, making it possible to accommodate 8 circuits on three of the unit-type bays already described. The bays are each 6 ft. 5 in. high and, with apparatus mounted, 1 ft. $5\frac{1}{2}$ in. deep; this includes the guard-rail projecting 7 in. from the front of the bay near the ground-level. Each section of bays is 5 ft. $1\frac{1}{2}$ in. wide, just half the space occupied at Leeds. The floor space required per circuit is slightly less than 1 sq. ft., and the average weight of a section of bays is $1\frac{3}{4}$ cwt. per foot run.

Assembly of apparatus.—A typical assembly of one suite of bays, with side elevation and rear view, is shown in Figs. 10A, B, and C. The system adopted as standard is

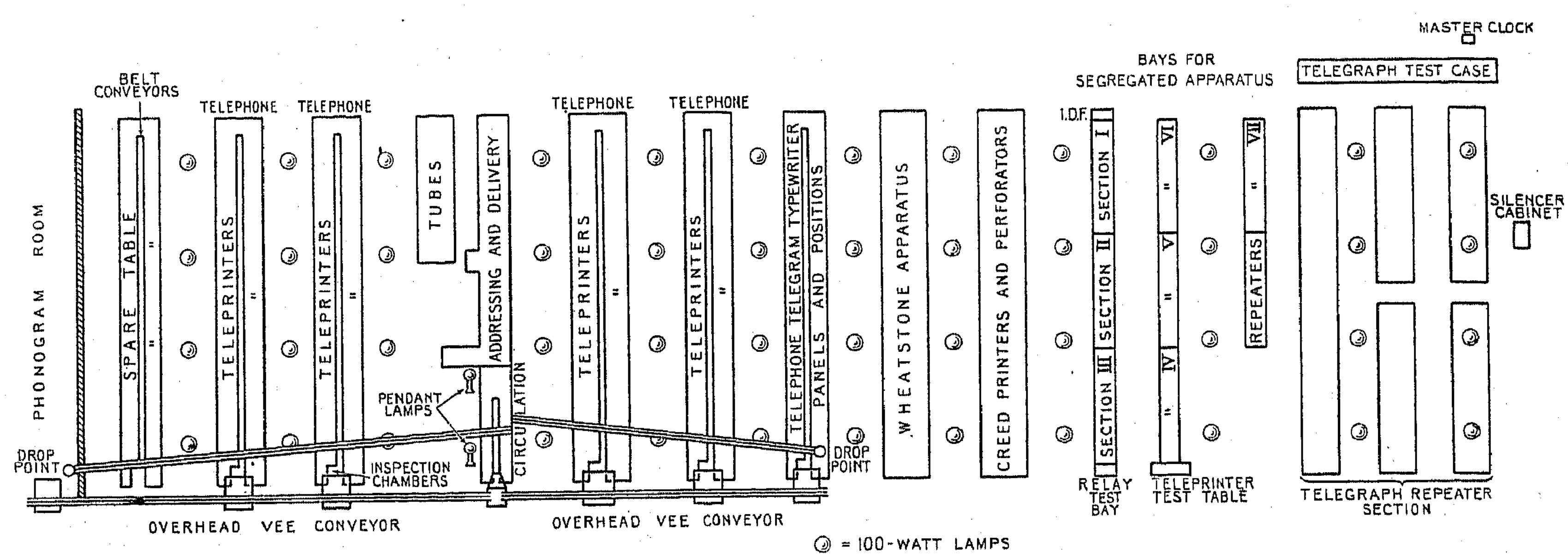

Fig. 8.—Lay-out of the Leeds telegraph instrument room.

SCHEDULE OF PANELS AND APPARATUS.

Schedule of Panel Apparatus.

Ref. No.	Functional detail	Labelling on panel
1	Line Relay	—
2	Sending Milliammeter	Sending
3	Receiving Milliammeter	Receiving
4	Reading Condenser	Reading Condr.
5	Reading Condenser Shunt	Reading Condr. Shunt
6	Vibrating Circuit Rheostat	A
7	Vibrating Circuit Rheostat	D
8	Vibrating Circuit Condenser	B
9	Line Milliammeter	—
10	Artificial Line Rheostat	R
11	Artificial Line Rheostat	R
12	Artificial Line Rheostat	R1
13	Artificial Line Rheostat	R2
14	Artificial Line Rheostat	R3
15	Artificial Line Condenser	C1
16	Artificial Line Condenser	C2
17	Artificial Line Condenser	C3
18	Vibrating Circuit Condenser	C
19	Line Battery Fuses	—
20	Loop and Local Battery Fuses	—
21	Line Battery Resistance Lamp	Line
22	Local Battery Resistance Lamp	Local
23	Resistance Lamp	Resistance
24	Test Teleprinter Resistance Lamp	Test Teleprinter
25	Leak Relay Resistance Lamp	Leak Relay
26	Leak Relay	Leak Relay
27	Leak Milliammeter	Leak
28	Test Milliammeter	Test
29	Teleprinter On and Off and Signals Return Switch	As stated in Functional Details
30	Test Set to Line or Local Switch	As stated in Functional Details
31	Morse or Resistance Switch	As stated in Functional Details
32	" G " Circuit On and Off Switch	As stated in Functional Details
33	Teleprinter On and Off Switch	As stated in Functional Details
34	Duplex or Simplex Switch	As stated in Functional Details
35	Test Teleprinter Incoming or Out-Signals Switch	As stated in Functional Details
36	Outgoing Leak Switch	Sets 1 to 8
37	Incoming Leak Switch	Sets 1 to 8
38	Fuse Testing	Fuse Test
39	Fuse Testing	Fuse Test
40	Telephone Circuit Jack	Telephone
41	Battery Voltage Testing	Voltmeter
42	Morse Circuit Sounder	—
43	Morse Circuit Key	—
44	Localization Testing	—
45	Outgoing Leak Circuit Shunt	—
46	Jack for Trolley Teleprinter	—
47	Power Socket for Trolley Teleprinter	—
48	Power Switch for Trolley Teleprinter	—
49	Test Jacks for Sets 1 to 8 and Test Apparatus	Sets 1 to 8
50	Balancing Operations	

Schedule of Back-of-Panel Apparatus.

Ref. No.	Functional detail
51	Surge Transformer
52	Frequency Filter
53	Shunted Condenser Circuit, etc.
54	Shunted Condenser Circuit, etc.
55	Tablet, 7 Test Hole, Fixed Resistance

Schedule of Panels, Etc.

Item	Functional detail
A	2 Loop Simplex C'ct with Relay Std. G.N., H.N., or 299 A.N.
B	Duplex, Loop or Single Wire C'ct with Relay Std.G.N.
C	Duplex, Loop or Single Wire C'ct with Relay Std.B.N.
D	Duplex, Loop or Single Wire C'ct or S.X. Special Event C'ct
E	2 Line S.X. C'ct C.B. System
F	Testing
G	Testing
H	Testing
J	Line Battery Universal Supply
K	Loop and Local Batteries. 80 V Supply
L	Resistance Lamps
M	Resistance Lamps
N	Voltage Test
P	Telephone Calling Indicator Lamp
Q	Guard Rail
R	Cable Channel

panel-mounting instead of rack-mounting as in the initial supply, the advantage being that if it is desired to vary the type of circuit in a section a change can be effected by one alteration instead of a number. Installation of panels of the type shown is now proceeding in the five largest telegraph offices, viz. London, Birmingham, Glasgow, Liverpool, and Manchester. The panels are aluminium, of a uniform thickness of $\frac{1}{4}$ in., with a crystalline, black enamel finish in front and black enamel behind. Panels are designed to function as (1) apparatus, (2) test, (3) fuse, and (4) lamp units.

Panel No. 1 carries the terminal line apparatus associated with a 2-loop simplex teleprinter circuit, and key-switches to set up the various testing conditions.

Panel No. 2 is similarly equipped, to provide for a duplex circuit using a relay of the vibrating type.

Panel No. 3 provides for a duplex circuit using a Standard B relay.

Panel No. 4 provides for a teleprinter circuit having simplex conditions at the distant office. The panel can be used for either simplex or duplex working, a key-switch making the necessary circuit alterations. This type of circuit is used in connection with race meetings and similar special events where traffic is mainly in one direction.

Panel No. 5 provides for a 2-line simplex circuit working on a short route. In this case there is no line battery at the out-station; one line is used as a power lead from a 24-volt battery at the Head Office.

Panels Nos. 6, 7, and 8 provide the testing apparatus.

Panel No. 9 carries 8 groups of 3 fuse mountings, 3 fuses being required for each independent battery circuit. Two busbars, each connected to 10 fuse mountings, are joined, respectively, to the positive and negative universal battery. These voltages are in use for the local circuit serving the teleprinters.

Panel No. 10 has 6 busbars, each connected to 10 fuse mountings, and 2 busbars connected to 5 fuse mountings. The former busbars are joined to the 24-, 40-, and 80-volt positive and negative universal battery, and the latter to the 120-volt supply.

These voltages are used for line batteries. The ten

panels enumerated are uniform in dimensions, i.e. 1 ft. 8 in. × $11\frac{1}{32}$ in.

Panel No. 11 carries 12 jacks to hold 12 carbon-filament lamps which are used as protective resistances in the battery leads. The advantage of using lamps in this position is that, should a short-circuit occur at the contacts of a relay or the transmitting contacts of a teleprinter, the resultant glow of the lamp calls attention to the circuit. This panel is 1 ft. 8 in. wide and 6 in. high.

Panel No. 12 is fitted with 3 jacks, to hold 3 lamps similar to those in the battery leads. They are used for balancing purposes only, and hence it is not necessary for them to be under observation. The panel is attached at the back of the bay, behind Panel No. 11.

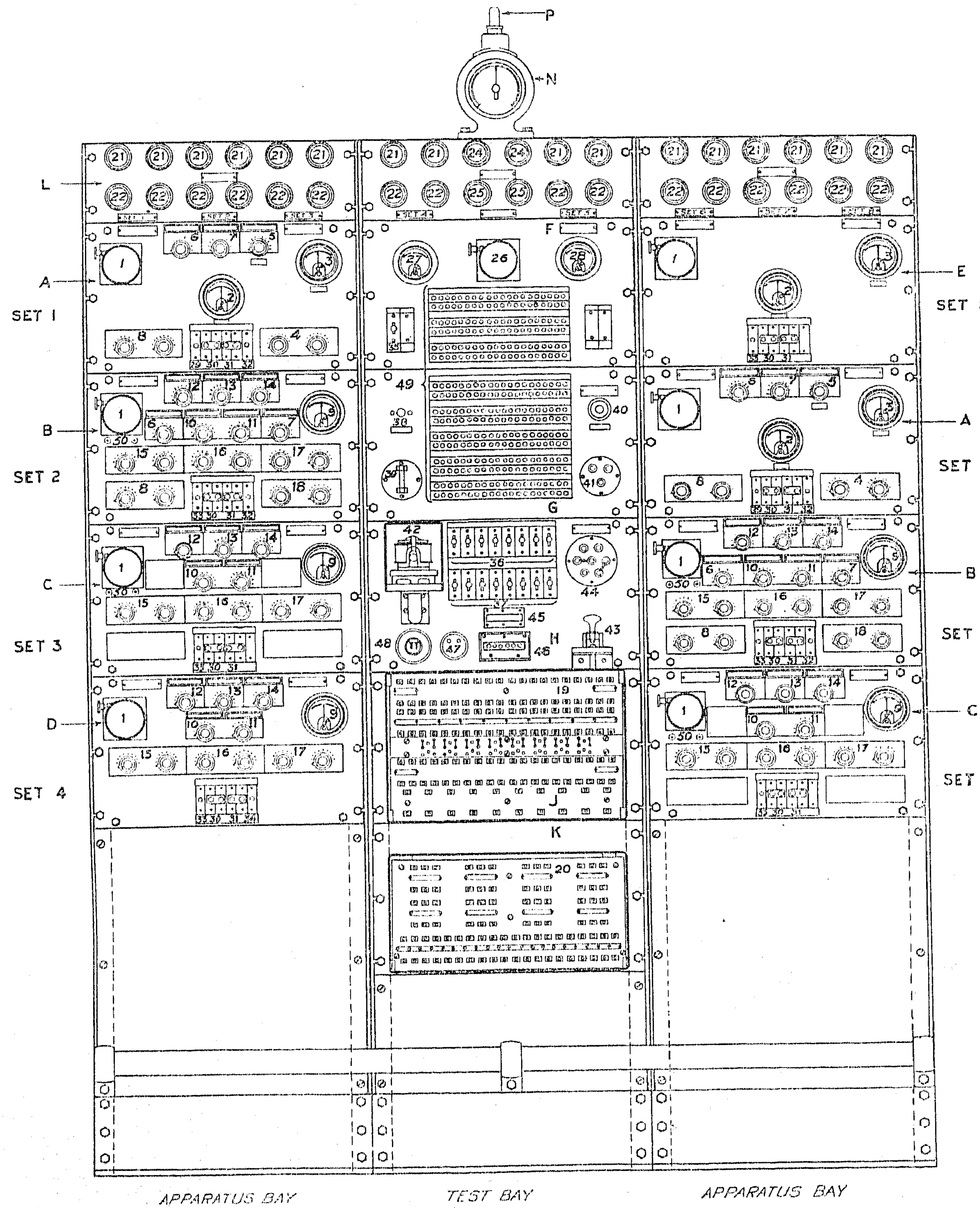

FIG. 10A.—Front view of standard panel-mounted equipment.

Each section of bays is fitted with 8 apparatus, 3 test, 2 fuse, and 6 lamp panels. The apparatus panels are numbered from the top left, Set 1, down to Set 4, and then from the bottom right, Set 5, to Set 8 at the top right. Observance of this order is important owing to its relation to the wiring and concentrator arrangements.

The panels, with the exception of those carrying the lamp jacks, are each attached to the bay by means of 6 hexagon-headed set-screws, $\frac{3}{8}$ in. × $\frac{7}{8}$ in. B.S.W. with washers.

Four thin rods project from the back of the panels; upon these a removable metal dust-cover slides and is fastened to the rods by external screws.

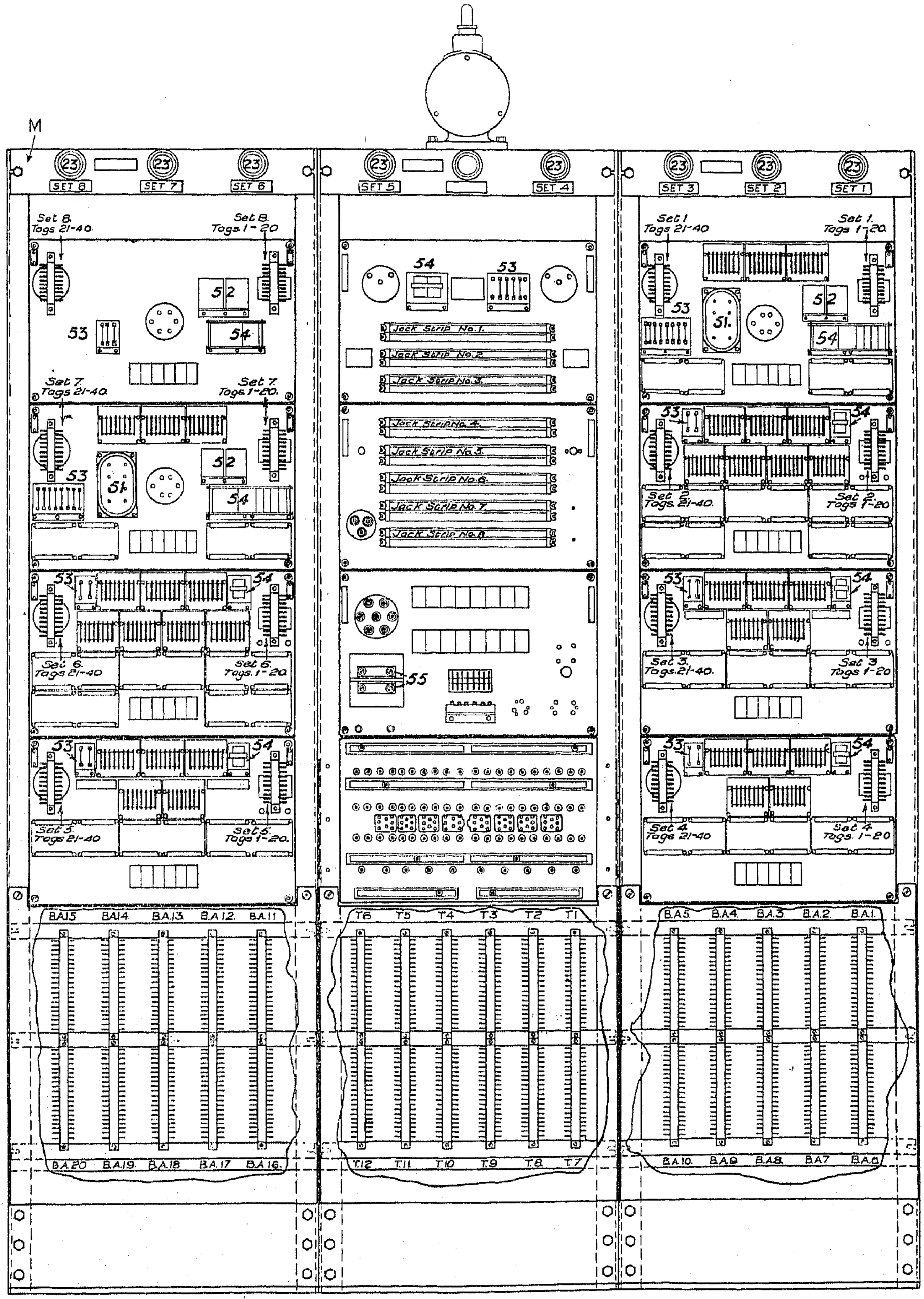

FIG. 10B.—Rear view of standard panel-mounted equipment.

Apparatus.—Post Office standard telegraph apparatus is, generally, unsuitable for panel mounting. It is bulky and heavy, and the plugs employed with rheostats,

condensers, and other units are liable to become dislodged. Apparatus of a new design has been introduced which is compact, light, and constructed to meet the

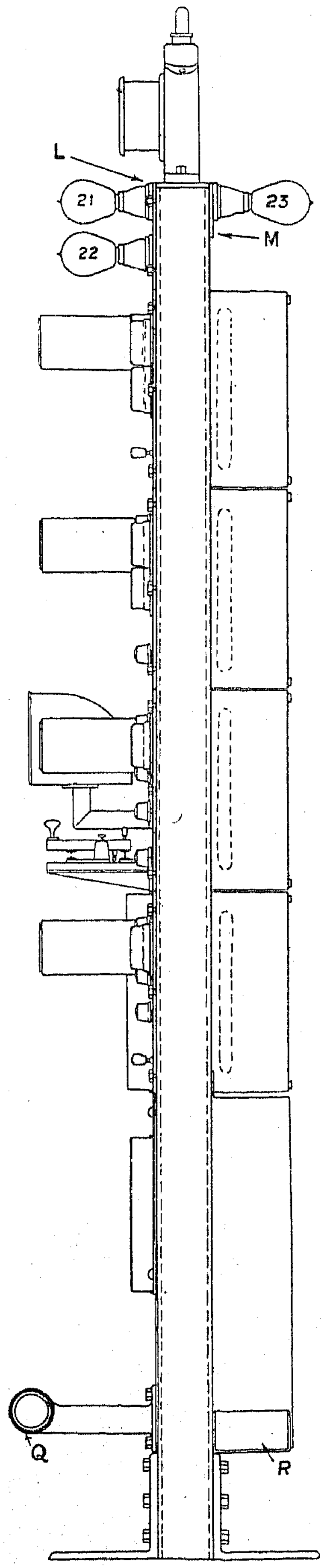

FIG. 10C.—Side elevation of standard panel-mounted equipment.

new conditions. The rheostats and condensers are adjusted by means of a knob-handle shaped to include a pointer. The values are shown on a dial marked on the panel. The knob is pivoted to a spindle which passes through the panel and also carries a metal brush or brushes which make rubbing contact with a ring of studs connected to the resistance bobbins or condenser units. Where plugs are necessary they take the form of a **U**-link with one leg tethered. Three types of rheostats and two types of condensers are employed:—

Rheostat R, giving 0–830 ohms by steps of 10 ohms
Rheostat S, giving 0–4 350 ohms by steps of 50 ohms
Rheostat T, giving 0–12 000 ohms by steps of 400 ohms
Condenser No. 3, giving $9 \cdot 9\ \mu F$ by steps of $0 \cdot 1\ \mu F$
Condenser No. 4, giving $5 \cdot 9\ \mu F$ by steps of $0 \cdot 1\ \mu F$

The Post Office differential galvanometer is replaced by a flush-mounted, moving-coil milliammeter, reading 30–0–30 mA. Experiments proved that the standard relay could be mounted in a horizontal position without loss of efficiency, and in view of the large stock of these instruments they have been dismantled from the wooden base in use and attached to a smaller base of mild steel. The new base engages a sub-base of similar metal mounted on the panel. The sub-base has 16 terminals, arranged in such a manner that either of the relays in service, i.e. Relays Standard BN, GN, HN, or 299 AN, can be accommodated. The terminals connected to the line and artificial line are brought out to two small pillars on the panel; these are for use when the circuit is being balanced. A small, sensitive voltmeter, reading 3–0–3 volts, has its terminals extended by cords to clips which fasten to the two pillars. The voltmeter is portable and is suspended from the relay by a strap while the testing officer is attending to the balance. This method of obtaining a correct adjustment is far superior to the old method of balancing by means of the line galvanometer.

Testing facilities.—Key-switches of the standard lever type are mounted on the apparatus and test-panels. The keys on the former enable the testing officer to set up the conditions necessary to:—

(1) Balance the circuit.
(2) Cut off the line batteries to allow the distant station to balance.
(3) Work Morse duplex to the distant station.
(4) Work teleprinter duplex to the distant station.
(5) Work teleprinter duplex to the instrument table.

The circuits made by the keys in their various positions are shown in Fig. 11. The figure shows the connections for Panel No. 2 or 3. The test-bay panels carry 16 rows of 5-point jacks arranged in pairs. Each circuit is allotted 12 pairs, and by means of the jacks the circuits may be cross-connected to other test bays by plugs and cord or connected to either of the test tablets. The jacks are interpolated in the circuit of (1) the lead from the centre of the line battery, (2) the A line, (3) the B line, (4) to (8) the five leads taken to the instrument table to serve the teleprinter, (9) and (10) local power supply for the line relay, (11) and (12) the A and B wires for the "send" line of 2-loop simplex circuits. The wiring of all testing apparatus is also taken through jacks. Positive and negative 40-volt batteries are connected to a standard Post Office 7-hole test tablet, which is also connected with the terminals of a test milliammeter. This tablet, in conjunction with the jacks, enables earth,

contact, or disconnection faults to be localized, either in lines or in local apparatus.

A voltmeter is mounted above the test bay and connected to a 3-hole test tablet. The equality of the batteries serving a teleprinter circuit is a matter of some importance, hence the generous supply of voltmeters to enable accurate and frequent tests to be made. A polarized sounder and Morse key is provided at each test bay for speaking purposes. A small lamp, connected to a fuse mounting and a 24-volt battery, is mounted at the left of the lower jack strips. This forms a test circuit for the 1-ampere fuses inserted in the battery leads.

When the testing officer is advised that a circuit requires attention the test teleprinter is connected to a jack on the test bay. Either leak key is thrown, as the nature of the trouble may require. If the fault is attributable to line or the distant office the circuit is terminated at the test bay by throwing the "Test set to line" key, and the matter is pursued. When the circuit is again satisfactory the "Test set to local" key is thrown and the instrument-table teleprinter advised that working may be resumed. The teleprinters in the operating field are not tested from the test bay; a machine under suspicion is replaced and taken to the test table for investigation. Thus the traffic end of the circuit is relieved of all testing duties, and the supervising officers are able to give their attention wholly to staff and traffic requirements.

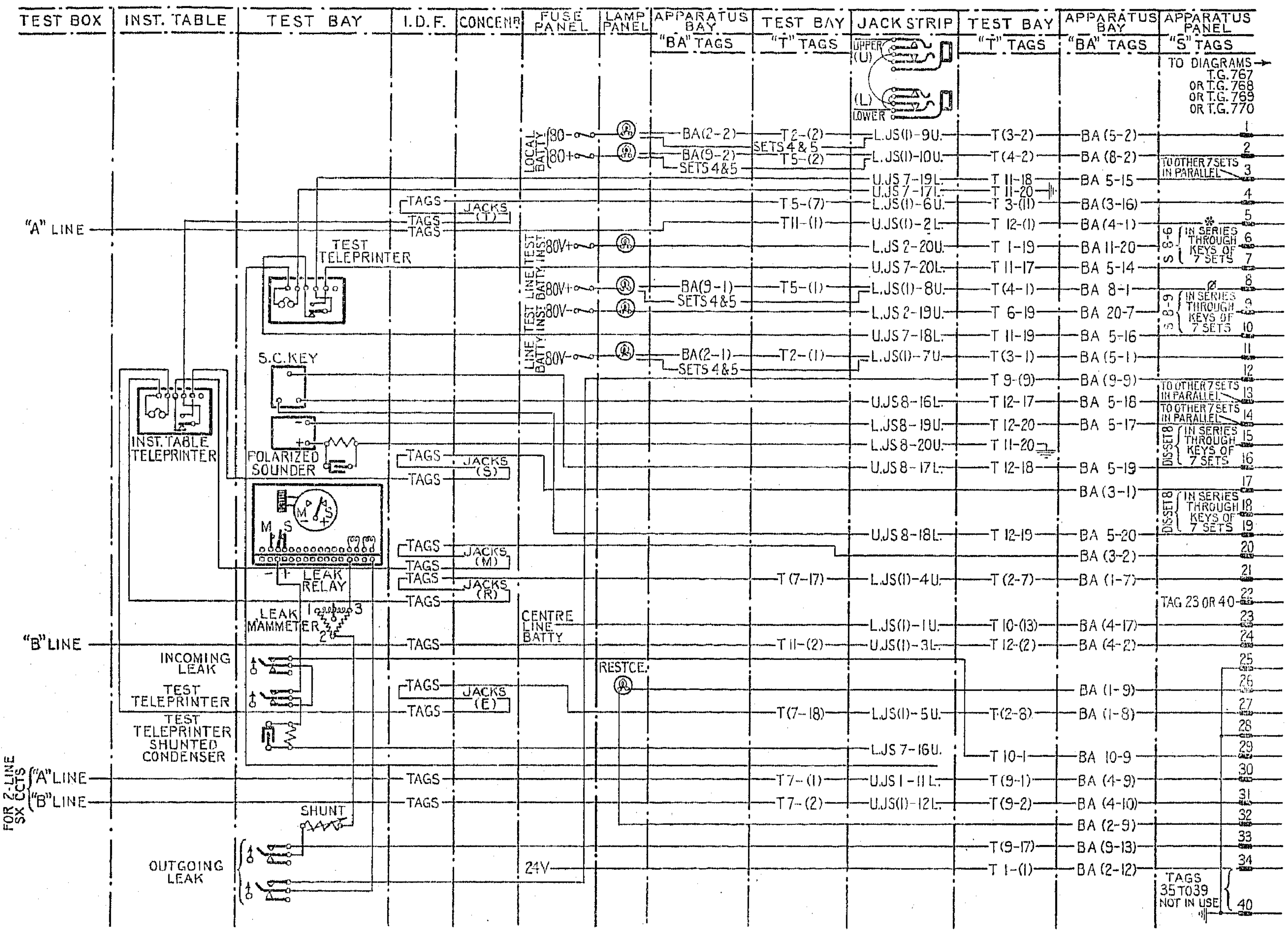

FIG. 11.—Schematic diagram of circuit connections. Test bay apparatus and connections.

Each of the 8 circuits has a key-switch in the outgoing and incoming circuits. The outgoing leak circuit consists of a variable resistance, of high value, placed in series with a relay. The introduction of the leak circuit has no appreciable effect upon the strength of the current in the line circuit, and, as the leak circuit is derived from a point between the teleprinter transmitting tongue and the centre of the line relay coils, no disturbance of the duplex balance is caused. The incoming leak circuit is obtained from the tongue of the line relay by means of a shunted condenser placed in parallel with the unit serving the instrument-table teleprinter.

The facilities provided enable an efficient officer to diagnose and locate a fault quickly and accurately without moving from the test bay. Testing instruments are in position and are brought into use by means of plug and cord or a key, hence no delay arises from screw terminals, soldered connections, or temporary leads. The scheme is a great advance on the old methods of fault localization. It aims at reducing to a minimum the time lost due to line or apparatus failure. It

should perhaps be mentioned that the main telegraph test box remains, and functions for all routine tests of the line plant. When the maintenance officer has definitely proved the existence of a line fault by means of the test-bay equipment the faulty line is replaced and taken over by the main test-box officer.

Power arrangements.—Power for the line current may be derived from an earthed battery, usually a universal battery, or a separate battery for a metallic loop circuit. With either type the voltages required may vary from

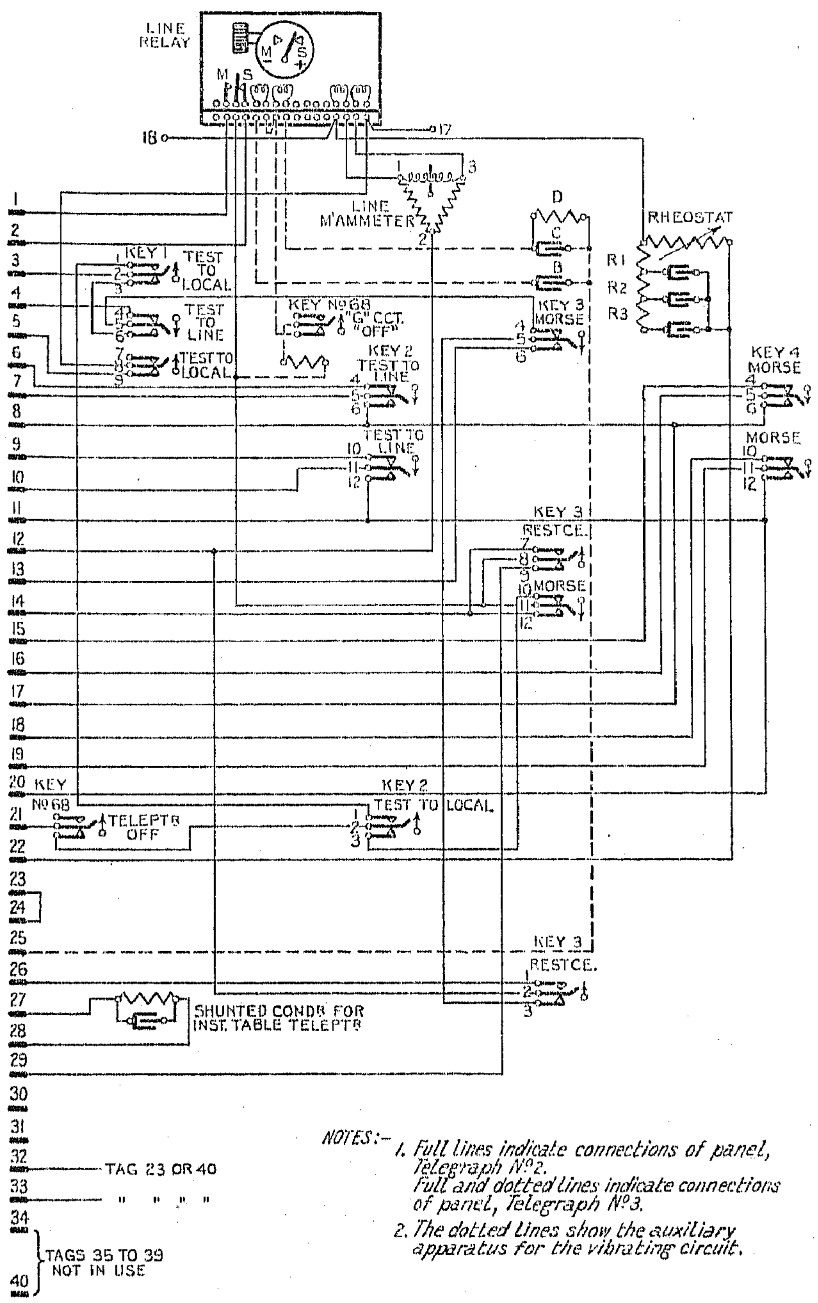

FIG. 11 (*contd.*).—Schematic diagram of circuit connections. Panel apparatus and connections.

24 to 120 volts. The wiring of the apparatus panels enables either of these methods to be used by the alteration of one wire. An earth connection, and a lead from the centre of a group of fuses arranged for a separate battery, are carried to the connection tags on each panel. The points usually connected, alternatively, to B line or earth are also carried to connection tags, and a bridge is made between tags as required. The fuse panel for the universal battery supply is shown in Fig. 12. Four voltages are connected to small sockets arranged in half circles. A **U**-link has one leg tethered in the socket at the centre of the half circle, the other limb being inserted at the required voltage. This arrangement allows each of the 8 sets to be connected to 40 or 80 volts, the values required for a large proportion of the circuits, and 50 per cent of the circuits to be connected to 24 or 120 volts, required in exceptional circumstances. The fuse panel is an improvement upon the fuse and distribution case in general use. Power-changes are quickly made without the risk of error. The fuse panel for the separate batteries and local supply is shown in Fig. 13. The loop-battery fuses are wired on the instrument side, the positive and negative leads being coiled ready for connection to the lamp resistances if a metallic loop circuit is in use. The "tap" fuse is wired to the test-bay jack strip in every case and carried forward to the apparatus panel.

Telephone facilities.—In the operating area of the instrument room a number of small switchboards each provided with 20 numbered jacks and 20 lamp indicators are placed on the instrument tables. Jacks with the same number are each connected in parallel to A and B lines run to the segregated apparatus. Here the lines are bridged by a line relay the circuit of which is closed when a telephone plug is inserted at a switchboard. The operation of the relay completes the circuit of an "engaged signal" relay having two local contacts. One contact connects an 80-volt battery to the "engaged" lamps of the particular number on all the switchboards. The second contact closes the circuit of the A line through one coil of a transformer and jacks labelled "telephone" on the test bay (usually four test-bay jacks are joined in series), then through the coil of a "calling" relay, returning to the B line via the test-bay jacks. The operation of the calling relay makes the circuit of four lamps, one placed above each voltmeter on the test bays, and by means of a second contact completes the circuit of a bell which is commoned to all sections. The testing officer has a portable telephone and communicates with the instrument table by inserting a plug in the "telephone" jack of either of the groups of test bays. These arrangements are shown in Fig. 14. Any desired communication from the test bays to the operating area is made by means of the normal house telephone system.

Concentration of circuits.—The ideal method of arrangement for the operating area of an instrument room is that which allows teleprinter working positions to be connected to any line circuit without reference to the type of circuit or interference with the balance conditions. Such an arrangement allows working positions to be grouped in a compact body, simplifies supervision, and economizes lighting. The instrument-room conditions that have obtained hitherto did not allow this arrangement, since line and local circuits are linked as one unit. The desired facility has been provided under the new scheme by means of concentrator panels. Strips of twenty 6-point jacks are attached to a bay of dimensions uniform with those described. Two strips are required for 20 circuits. A jack on the upper strip is connected to 5 leads associated with an apparatus panel, and the jack immediately below it is connected by five leads to a teleprinter position. The concentrator bay has jacks to accommodate 80 circuits. The wiring of one circuit is shown in Fig. 15. By means of two

6-point plugs of the flat-spring type, and a connecting cord, line jacks may be cross-connected to instrument jacks as desired, with only a momentary disturbance of the line conditions.

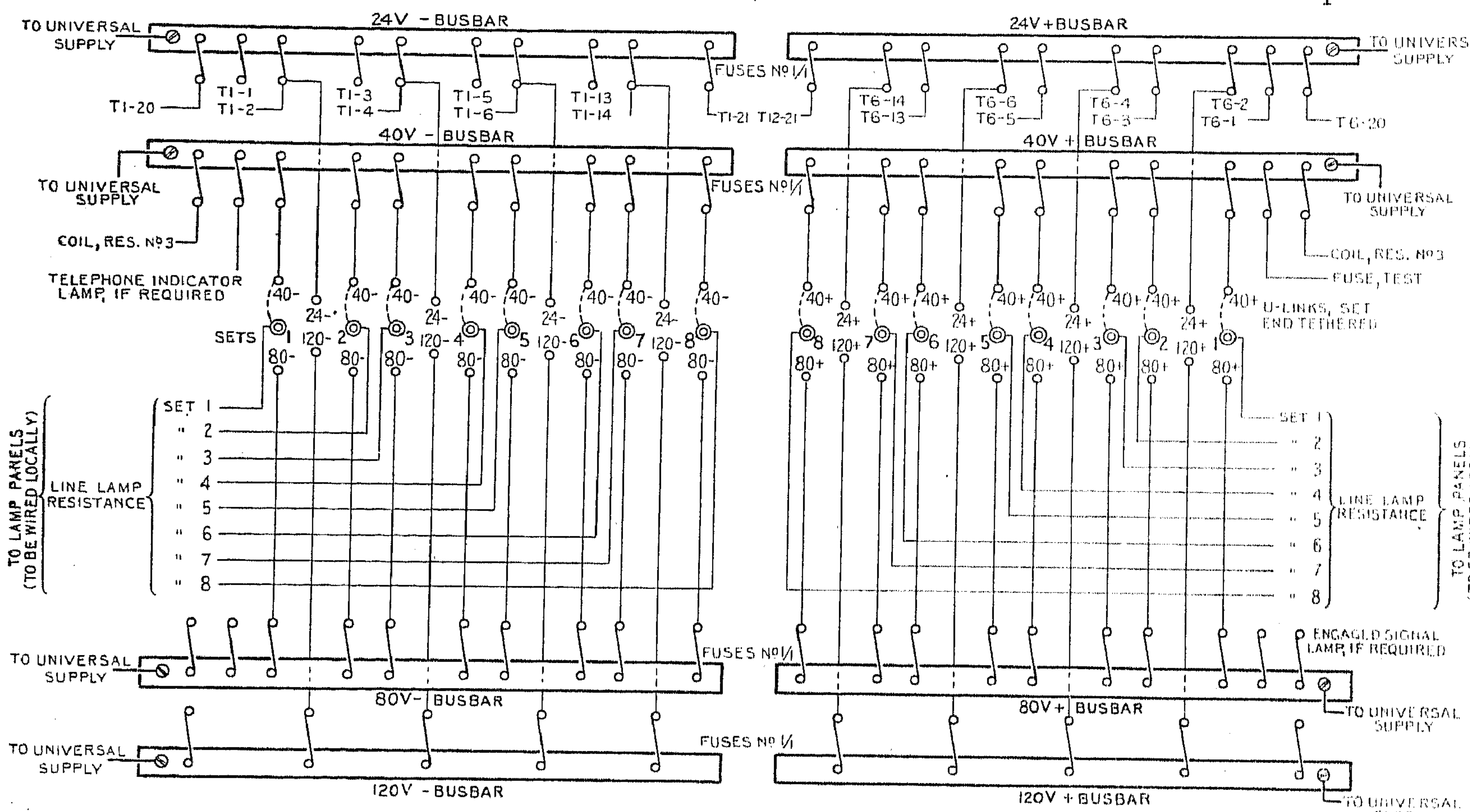

FIG. 12.—Fuse panel for universal battery supply. Connections to apparatus shown on other diagrams:—
T1–1 indicates a strip connection on the test bay. T1 defines the position of the strip, and the final group indicates the tag number.

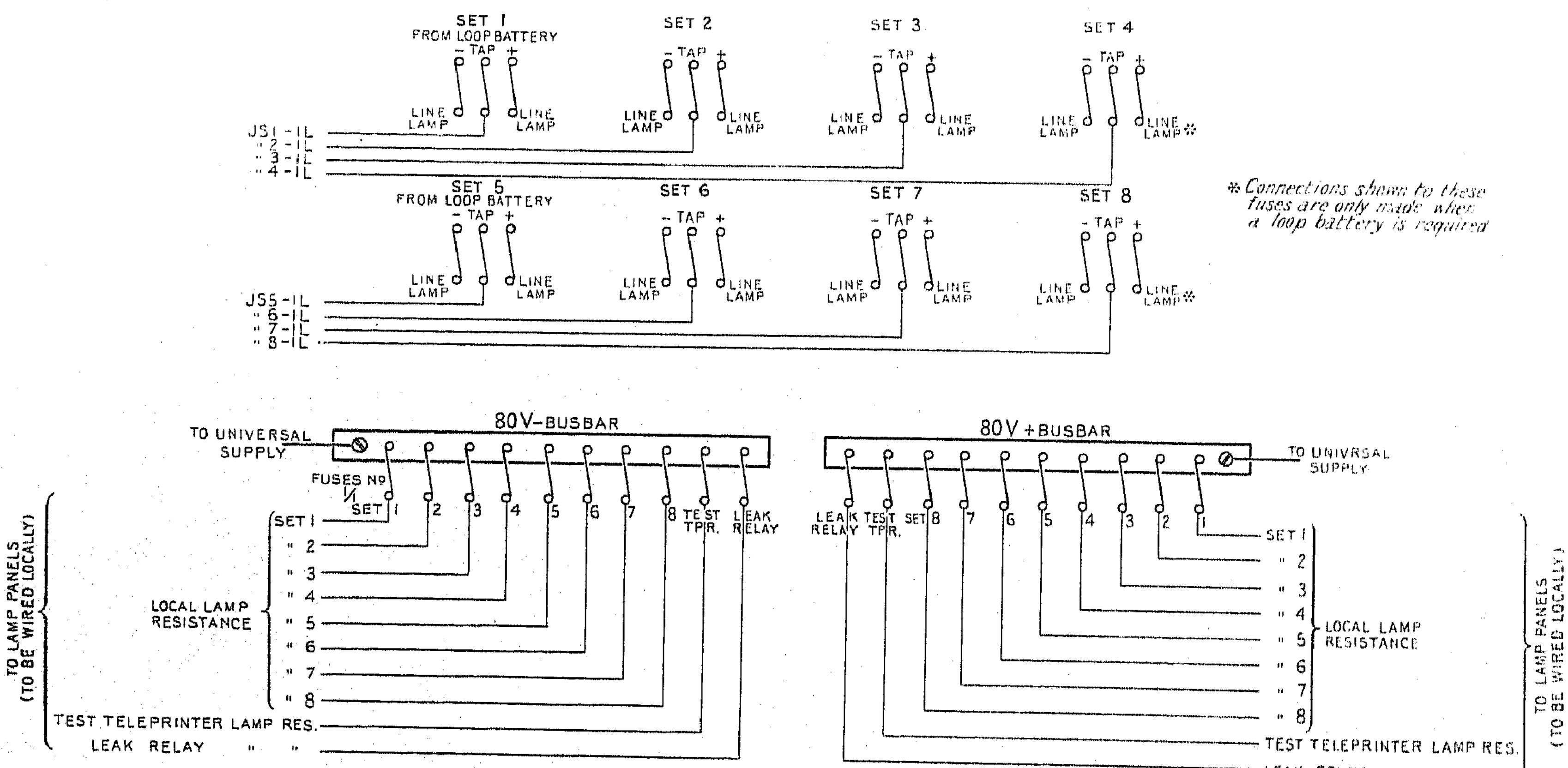

FIG. 13.—Fuse panel for separate batteries and local supply. Connections to apparatus shown on other diagrams:—
JS1–1L indicates a jack strip on the test bay. JS1 defines the positions of the strip, and the final group indicates the jack number and whether upper (U) or lower (L) row.

Wiring of bays.—An apparatus panel has two connection strips with 20 tags mounted on the back of the panel, one at each side. The apparatus on the panel is connected to these tags which, on the external side, are wired to similar tags on connection strips mounted at the bottom of the apparatus bay. From these the connections are wired across to connection strips on the test bay or other points as required. The apparatus on the test panels is wired direct to connection strips at the bottom of the bay. No intermediate point is required,

FIG. 1.—The Central Telegraph Office. A teleprinter section.

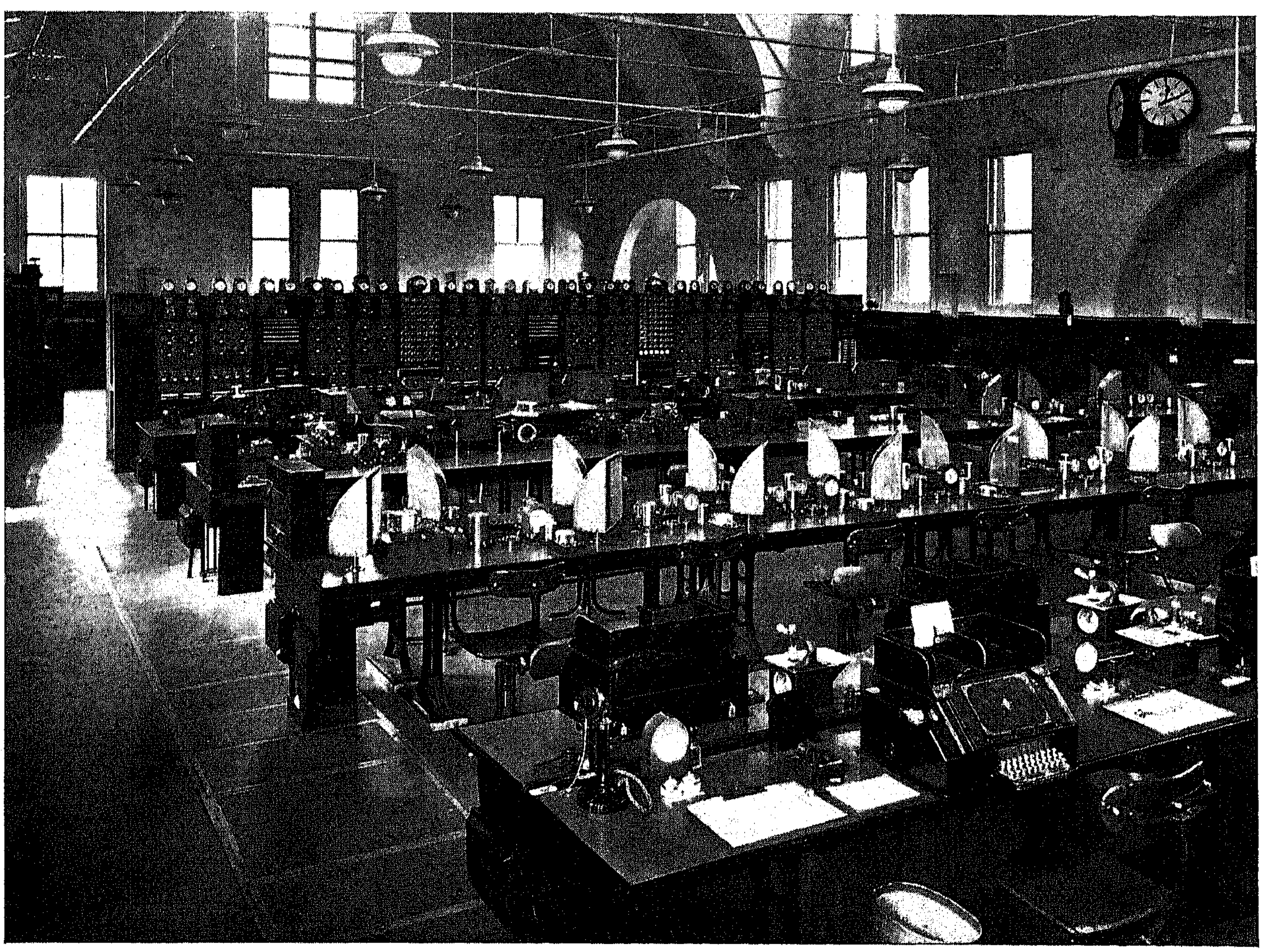

Fig. 9.—Rack-mounted apparatus in position at Leeds.

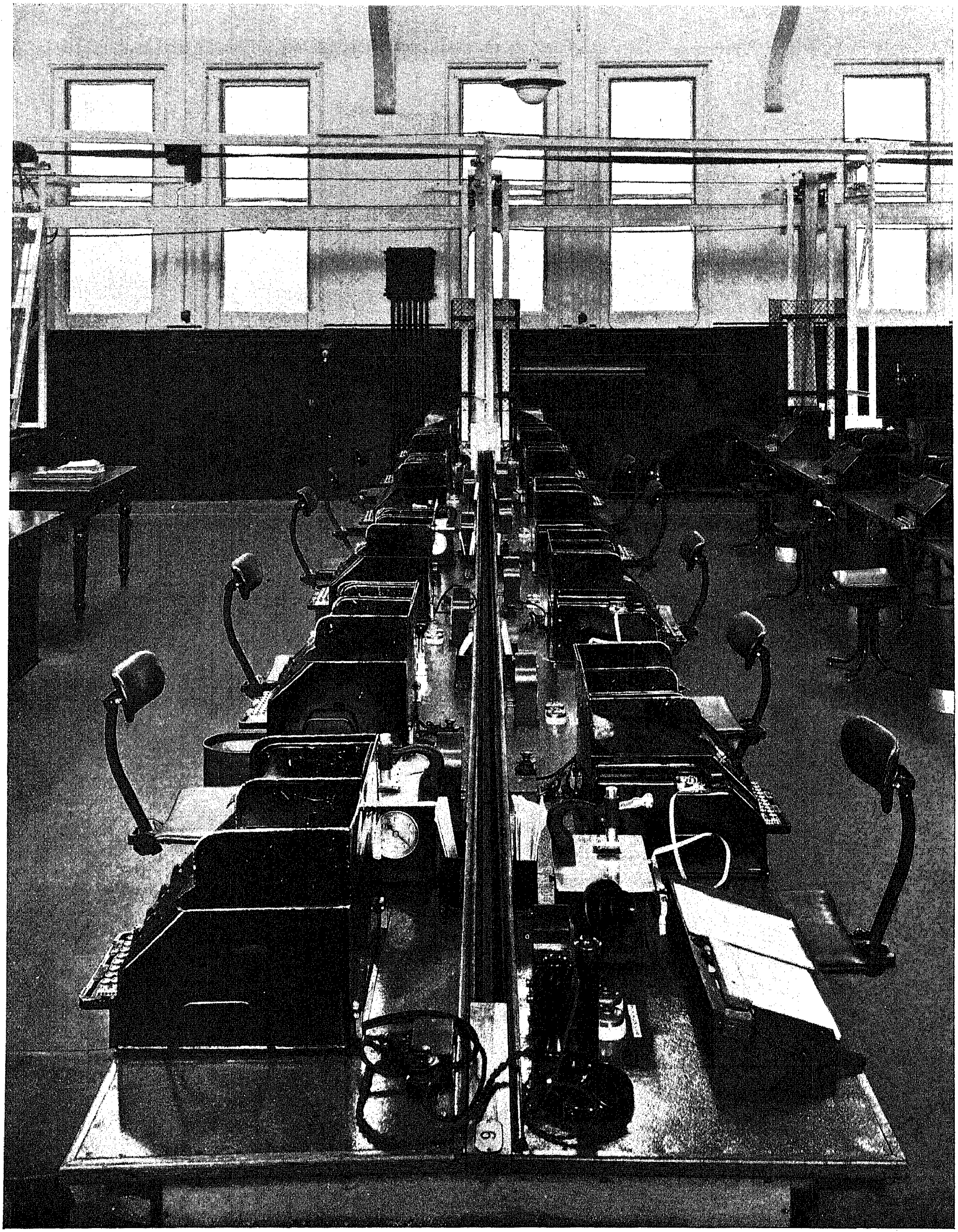

FIG. 21.—Instrument table, new style, with V conveyor.

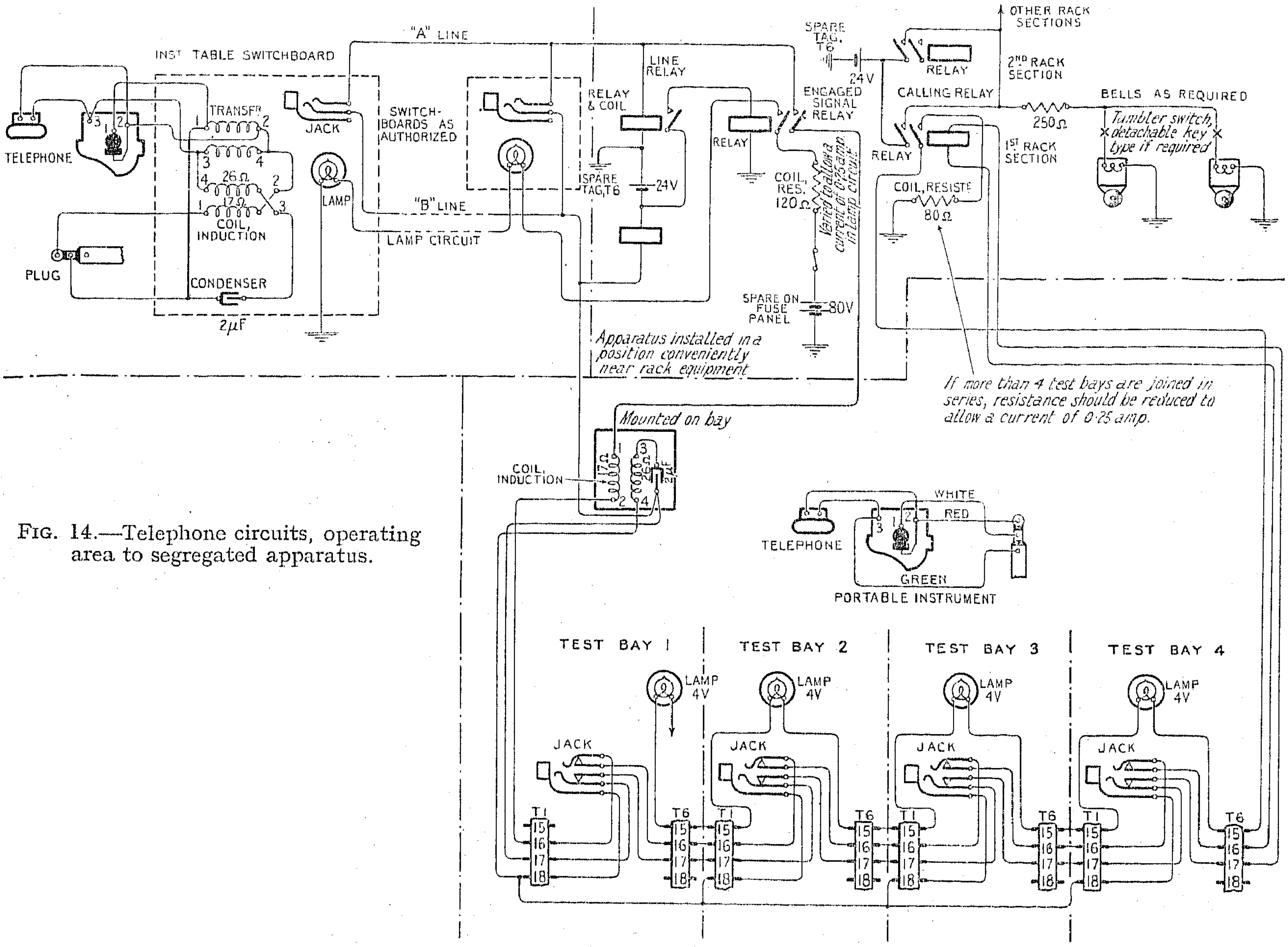

FIG. 14.—Telephone circuits, operating area to segregated apparatus.

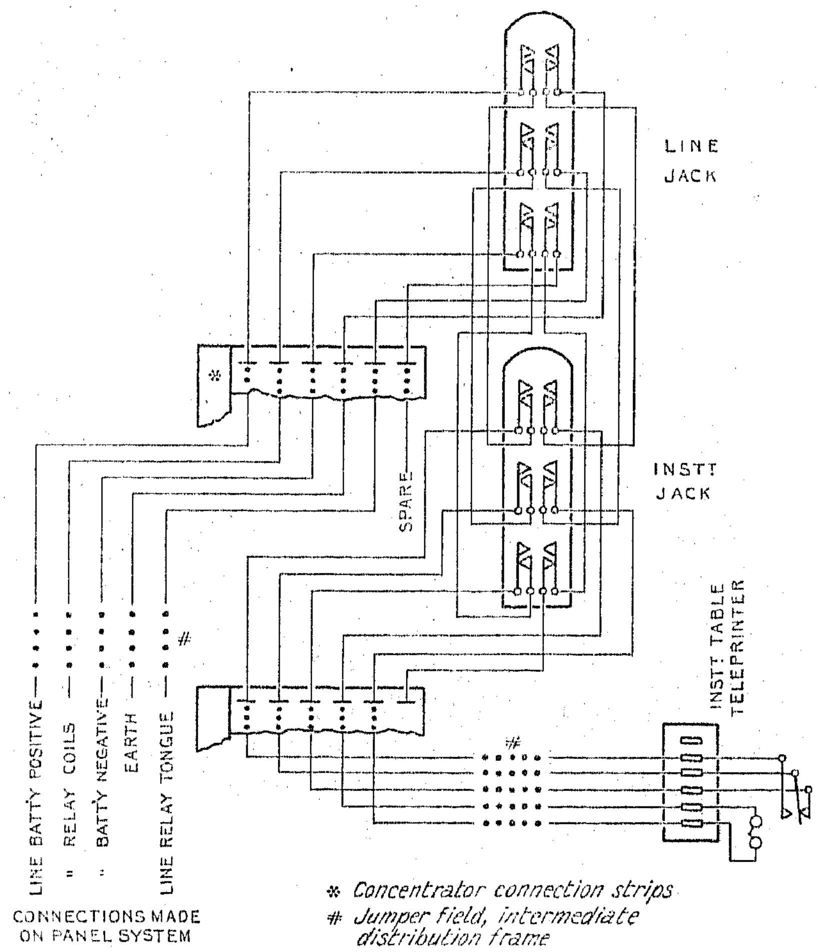

FIG. 15. Concentrator connections for teleprinter circuit.

since the type of panel is not subject to alteration. A small rectangular trough 4 in. × 3 in. is affixed to the bays at the rear near the floor-level to carry inter-bay cables. The wiring scheme for one section of bays is shown in Fig. 16. A separate cable for each teleprinter position is run from the intermediate distribution frame. floor was strengthened by the addition of rolled-steel joists, the bays being fixed in position on a concrete bed built up to 2 in. below the floor-level. Fig. 17 shows a vertical transverse section of an apparatus bay fixed in position. At the Central Telegraph Office, London, it was sufficient to place 6 in. × 3 in. channel transversely

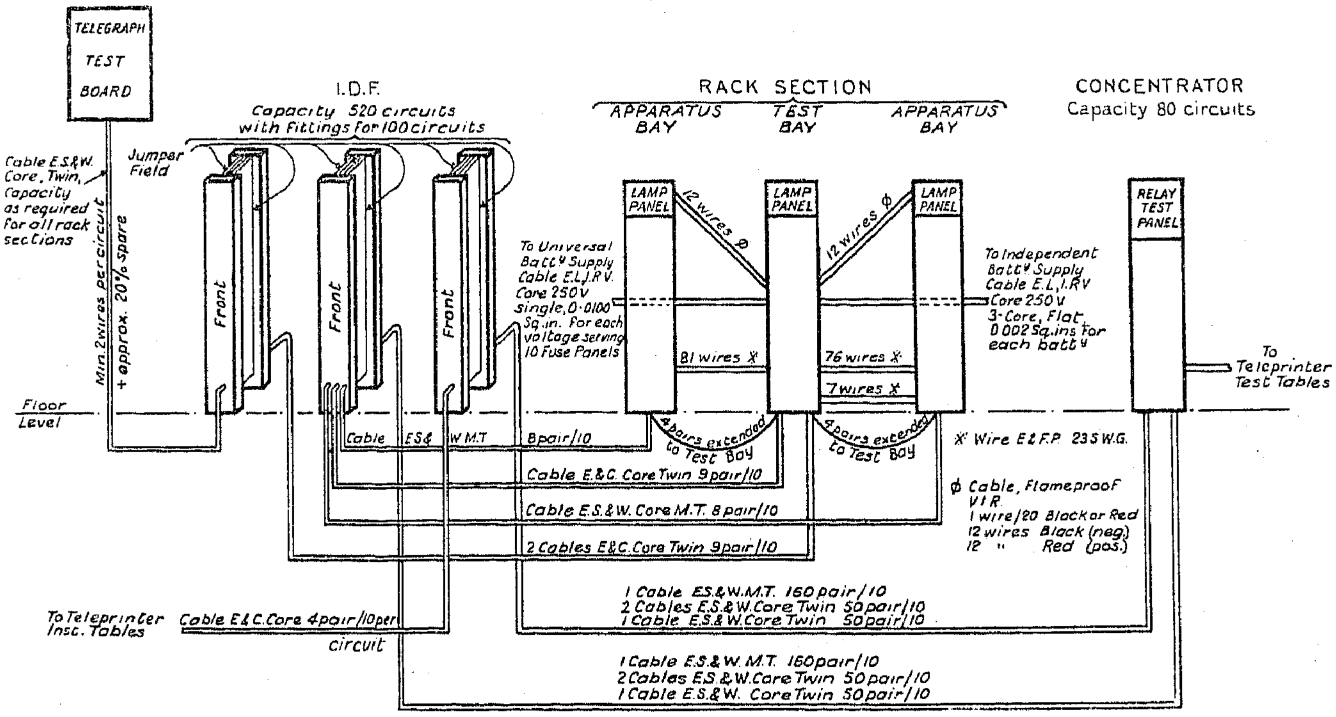

FIG. 16.—General system of wiring for bays.

This provision adds slightly to the cost but prevents the interference liable to occur where a cable of large capacity is employed.

Erection of bays.—The General Post Office in a large provincial town is, in most cases, a building of an old

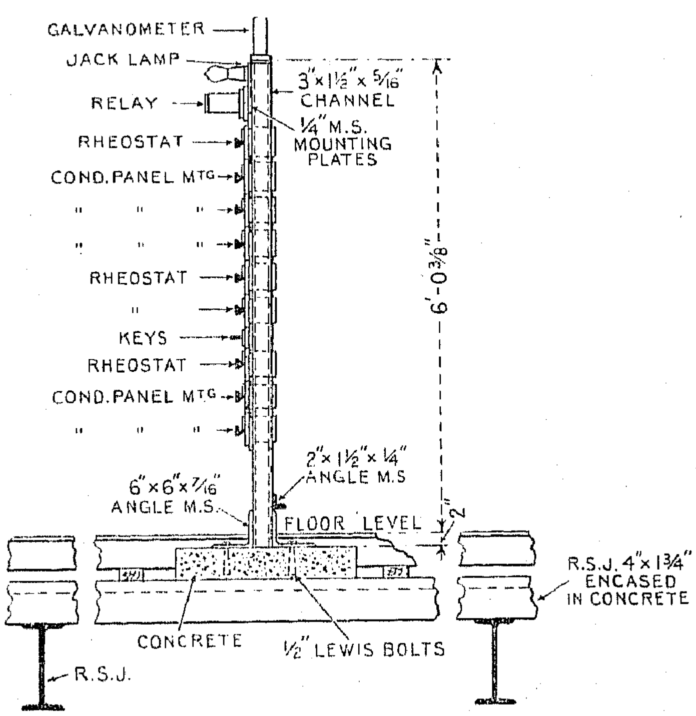

FIG. 17.—Fixing of bays. Leeds system.

type; the floors are not intended to carry a heavy load concentrated upon a small area. The introduction of the new equipment weighing approximately 10 cwt. for 8 circuits has, in most cases, necessitated structural alterations. Each office has to be considered separately, as the conditions are widely different. At Leeds the upon the existing joists, thus spreading the weight of the equipment. The additional supports are spaced 9 in. apart; the base of the bays is sunk 2 in. below the floor-level and bolted in position.

The front and side elevations of a section of racks in position are shown in Fig. 18.

Relay test panel.—A relay test panel is mounted above the jack strips on the concentrator. The arrangement of apparatus and testing facilities resembles closely that described by Messrs. Kingsbury and Goodman in their paper entitled "Methods and Equipment in Cable Telegraphy."* Testers of this description are new to the telegraph service, and good results have followed their introduction.

Teleprinter test table.—On long underground circuits, distortion of the signals necessitates correct adjustment of the teleprinter local circuit in order to avoid faulty reception. Strict neutrality of the armature of the electromagnet is one of the points that need careful attention. The armature is biased by two screws situated at its rear end. If the neutrality of the armature is tested by moving it from one pole-piece to the other by hand, in certain machines neutrality is shown over an area represented by as much as four turns of a screw. This method of adjustment cannot be relied upon where teleprinters are required to work on difficult circuits. The Autoplex, an instrument designed to measure the pull upon the armature in pounds or ounces, has been tried, but when operated manually it does not give uniform results. A teleprinter test panel, table-mounted, has now been designed and brought into use with the object of standardizing the adjustment of the electromagnet.

* *Journal I.E.E.*, 1931–32, vol. 70, p. 477.

The apparatus and key-switches allow four tests to be made:—

(1) The tongue of the teleprinter is connected to the coils of its electromagnet so that the keyboard signals are printed.
(2) The teleprinter is worked under duplex conditions to a second teleprinter brought to the table on a trolley when required.
(3) The electromagnet is tested for sensitivity by means of a variable resistance and milliammeter in the feed circuit.
(4) The electromagnet armature is tested for neutrality by means of a reverse-current key operated when the limit of sensitivity is reached.

These facilities are being supplied to all offices having several teleprinters, and where panel-mounted apparatus is not installed a relay test-panel is also mounted on the table.

Telegraph Repeaters.

Repeaters have been in use in the telegraph service since it was transferred to the State in 1870. The apparatus required is mounted on a baseboard measuring 3 ft. 6 in. in width, and 2 ft. 4 in. front to back; the amount of apparatus and its lay-out has varied to meet circuit requirements, but in essential features the boards in use to-day (there are about 170) resemble the earliest issues. The introduction of teleprinter working on practically all long-distance inland circuits gave rise to difficulties at the repeater stations. A teleprinter circuit has a marking current on the line during idle periods, whereas other systems in use send out a spacing current. Consequently the alarm unit in use with the repeaters, which operates with a marking current of 12 to 15 seconds' duration, will not function. The leak circuit of a repeater is provided with a Wheatstone receiver by means of which the accuracy of the duplex balance and the character of the passing signals may be checked. This provision is adequate for Wheatstone or Baudot circuits, but does not meet the requirements of a teleprinter circuit. A general demand arose for facilities to enable a teleprinter to be used in the leak circuit and, also, to enable either side of a repeater to be terminated and worked teleprinter for testing purposes. Temporary arrangements were made for the provision of these facilities where repeater boards are in use, whilst a better solution is being sought in the direction of panel-mounted apparatus.

Leeds is the second largest inland repeater office in the country, having accommodation for 16 repeatered circuits. The success of the rack-mounted equipment for terminated circuits led to the design of a section of repeaters embodying the same principles. Provision was made for four repeaters, each to accommodate either duplex or 2-loop simplex circuits. Key-switches are provided to enable either, or all, of the repeaters to be terminated and the two sides worked to Leeds as independent circuits. The value of this provision is that, should the line circuit on one side of the repeater fail, the office still through to Leeds is able to unload the traffic upon that station without the further delay involved in transferring the line and balancing a second apparatus set. Against the practical value of this dual function must be set the additional key-switches and somewhat complicated wiring that are involved. It is probable that the terminated condition will be dispensed with for future installations in order to simplify the circuits. The repeaters were brought into use at Leeds in October 1931 and have proved entirely successful. The racking dimensions, construction, and erection are the same as for the earlier equipment, but additional apparatus is mounted to provide for an alarm circuit and the 2-loop simplex condition. The alarm is operated by a spacing current on the line for 12 to 15 seconds. The tongue of the relay in the line circuit on each side of the repeater is connected to a leak circuit consisting of a Post Office relay and a fixed resistance to limit the current in the leak circuit to 10 mA. A 2-μF condenser is connected to the tongue of the alarm relay, an 80-volt battery through a resistance pencil of 5 megohms to the marking contact, and one coil of an earthed drop-indicator to the spacing contact. The effect of a spacing current upon the line relay is to place the alarm relay tongue on the marking side. The 2-μF condenser is therefore charged, but slowly, owing to the high resistance. At the end of the specified period the tongue of the relay returns to the spacing side and the condenser

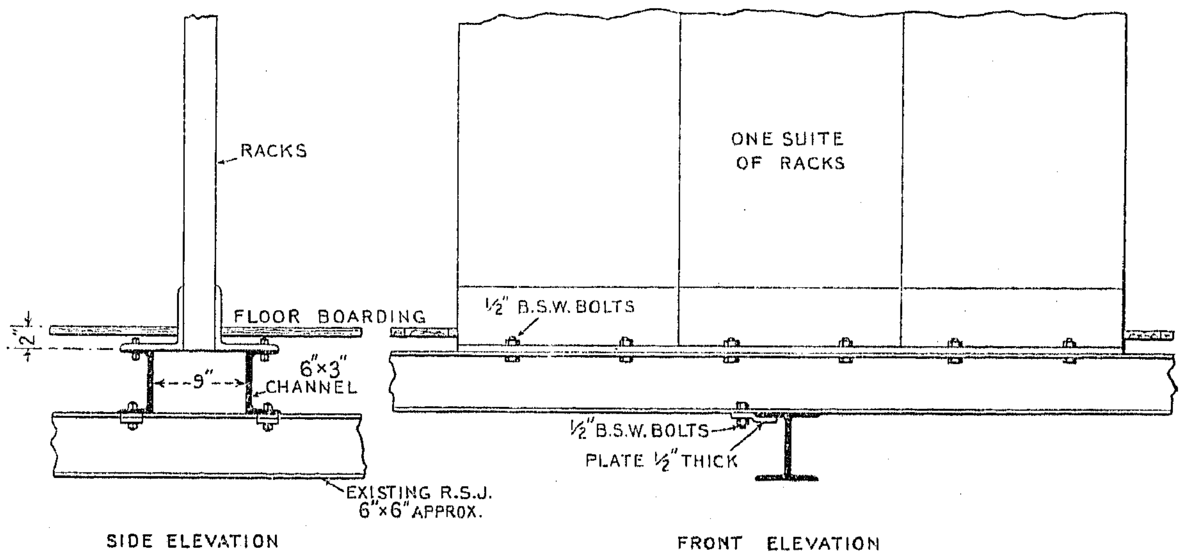

Fig. 18.—Fixing of bays. London system.

discharge is sufficient to operate the indicator. A shutter is released and closes a local circuit having a lamp mounted on a pillar placed above the bay, and a bell joined in series. The attention of the repeater station is thus gained and, by means of a key-switch, the alarm is cut off and a Morse key and sounder are brought into circuit for speaking purposes. A schematic diagram of the alarm circuit is shown in Fig. 19. A programme for the supply of rack-mounted repeaters to other offices is in hand; the new work will, however, follow the standard design for panel-mounted apparatus.

Labour-Saving Devices for Telegraph Circuits.

It is the duty of the receiving operator on a teleprinter circuit to attach the paper tape on which the message is printed to a telegraph form, check the number of words, detect any errors that may have occurred during transmission, and time and insert circuit details in a space provided on the form. The number of messages received frequently exceeds 70 per hour on busy circuits and, since it is imperative that the tape should be dealt with

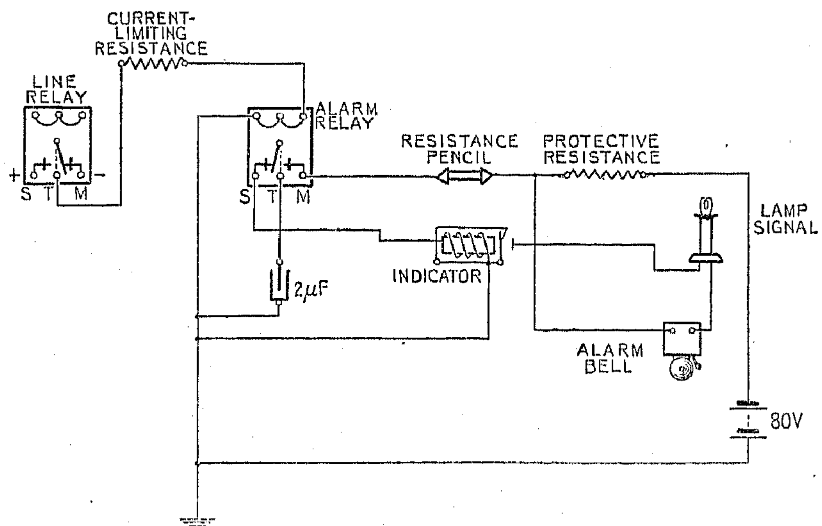

Fig. 19.—Telegraph repeaters. Alarm circuit.

immediately a message is completed, the operator is somewhat heavily pressed. The same difficulty existed on multiplex circuits, and the efforts now being made to discover appropriate methods of relieving the strain are but a continuation of former experiments.

Equipment provided at certain large offices includes:—

(1) Timing stamps and numbering machines.
(2) Gumming desks and bottle moistening wheels.
(3) Thimble tape cutters.
(4) Message forms of a new design.

Timing Stamps.

Twelve Blick "universal" timing stamps are installed on the receiving side of the busiest teleprinter circuits at Leeds. The stamps are operated manually and give an impression upon the message form, which is placed in position face downwards, of the hour, minute, a.m. or p.m., and the circuit designation. The clocks incorporated with the stamps are designed to operate with a current of less than 50 mA, given at half-minute intervals from a synchronized master clock of the Post Office pattern. Fig. 20 shows the circuit details. The machine weighs $12\frac{1}{2}$ lb. and occupies $63\frac{1}{2}$ sq. in. of the instrument table.

Other types of timing stamps have been introduced experimentally at selected offices to determine which machine is favoured by the operating staff.

Stromberg pattern.—This timing stamp is operated by a synchronized Post Office master clock giving an impulse at 1-minute intervals. The clock of the stamp is carried in the head of a pivoted arm, which also carries the inked ribbon and type wheels for giving an impression upon the message form. The platform upon which the message is placed for timing has a hinged projection; the act of placing the message in position slightly depresses the hinged portion so that a contact is operated, closing the circuit of a powerful electromagnet and causing the arm to drop upon the platform with sufficient force to give an impression upon the message of the clock time and circuit details. This machine is rather cumbersome, weighing $21\frac{1}{2}$ lb. and occupying $87\frac{1}{2}$ sq. in. of the instrument table. Apart from these disadvantages the stamp is a very reliable and useful unit.

Another stamp tried out was operated by a pedal

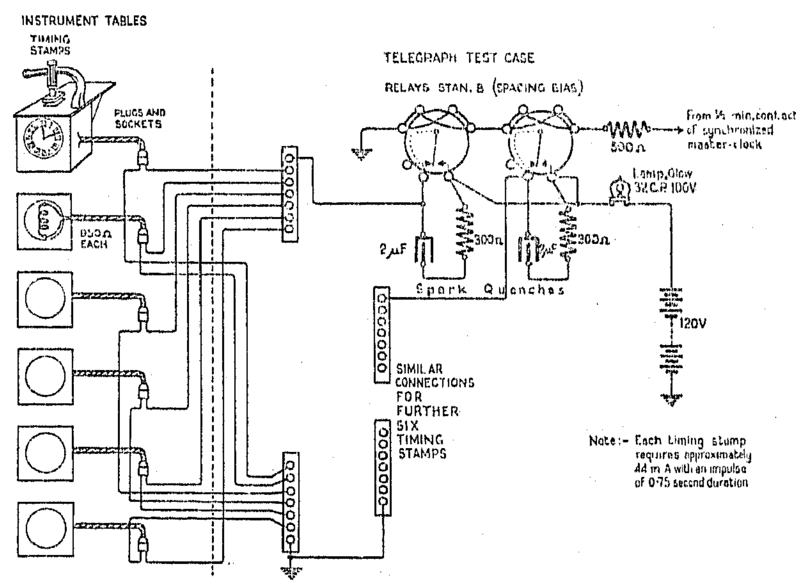

Fig. 20.—Timing stamps, circuit details.

placed on the floor. This type was not favoured by the staff, and proved troublesome.

The Warwick chronostamp.—A small stamp which, lifted bodily, gives an impression upon the message form of a clock dial with arrows indicating the time, the arrows being rotated by the clock movement. The chief disadvantage of this stamp is the blurred impression that is given unless the stamp is frequently cleaned and carefully used.

The most recent and promising machine is one which combines the particular features of the Blick and Stromberg patterns. The body of the stamp is sunk in the instrument table; it is wholly electrical, and is supplied with a series of rotating discs which supply a serial number in addition to the time, when in use on the transmitting side of a circuit. A considerable number of machines of this type have been introduced.

Gumming desks and bottle moistening wheels.—Gumming desks have been supplied for use on the receiving side of a circuit at a number of offices. The wooden desk, measuring 1 ft. $8\frac{1}{2}$ in. $\times$ $9\frac{1}{2}$ in., slopes to the operator at an angle of 45°. The right-hand portion of the desk has a shallow rack to receive the check sheet on which the serial numbers of the messages are recorded. A

metal clip is affixed to the left-hand edge of the board. This serves to hold the message forms in position whilst the printed tape is being attached; immediately above the forms a narrow raised platform is fixed on which pieces of tape which should not appear on the message form may be deposited. At the top of the desk, on the right, clips are provided to support a transparent bottle moistener, whilst on the left a felt moistener is attached. The bottle moistener contains a wick immersed in water, a small portion protruding at the nozzle of the bottle. The gummed tape is threaded beneath a spring, over the protruding wick, and through an aperture; it is drawn out, as required, for attachment to the form. The moistener is held in the right hand of the operator and a thimble tape cutter worn on a finger of the left hand guides the lines of tape on to the form and serves to make a clean break where required.

Given a continuous flow of traffic, this method of dealing with the tape is extremely useful. The "gumming" operation occupies a minimum of time, but on a lightly loaded circuit there are disadvantages. The message last received must suffer delay or, alternatively, slip must be pulled through and wasted between messages.

An endeavour is being made to avoid the use of check sheets by issuing message forms bearing numbers 1 to 100 bound in a pad. The received messages, also numbered in sequence, are gummed to the appropriate form, and the correspondence of numbers leads to the detection of an error in numbering or a missing message.

CONVEYORS.

The instrument tables at Leeds are 1 ft. 9 in. wide, with the exception of one wider table in use experimentally. They are placed in pairs with a space of 2 in. between each table and a gangway of 5 ft. between each two adjoining pairs of tables. Six double tables are provided with conveyors which run between and below the level of the tables. Access to the conveyors is obtained by means of a V-shaped channel, 1$\frac{7}{8}$ in. wide at the top, narrowing to $\frac{7}{8}$ in. at a depth of 5 in. The sides of the channel are of No. 16 S.W.G. sheet steel. Fig. 21 (Plate 2) shows a double table, and Fig. 22 a sectional view of the conveyor. At the base of the channel a continuously running endless belt, 1$\frac{7}{8}$ in. wide, travels at a speed of 160 ft. per min. A separate motor is provided to drive each belt. The message forms are dropped into the channel and travel on edge to the end of the table, where they are discharged into a riser belt (see Fig. 23). The rollers of the riser belt are arranged in such a manner that the messages are taken from the table V conveyor in a vertical position, turned into a horizontal position, and delivered by the belts into an overhead V conveyor. Two overhead V conveyors, each fed by three riser belts, run at right angles to the instrument tables at a height of 9 ft. from the floor-level and converge at the circulation table, where the messages are delivered via a reinforced glass chute, with hinged front, on to a slow-moving band, 9 in. wide, travelling along the centre of the table.

In addition to the system for collecting received messages, messages for dispatch are conveyed from the circulation table to two drop-points, the phonogram room and the concentrator. The two riser belts serving these points are fed by hand through chutes; at the bottom of the chutes the messages are gripped between two belts and are conveyed vertically to a height of 10 ft. and then horizontally to the points mentioned. The belts release the messages above a bead curtain chute, down which they fall on to the table. Messages

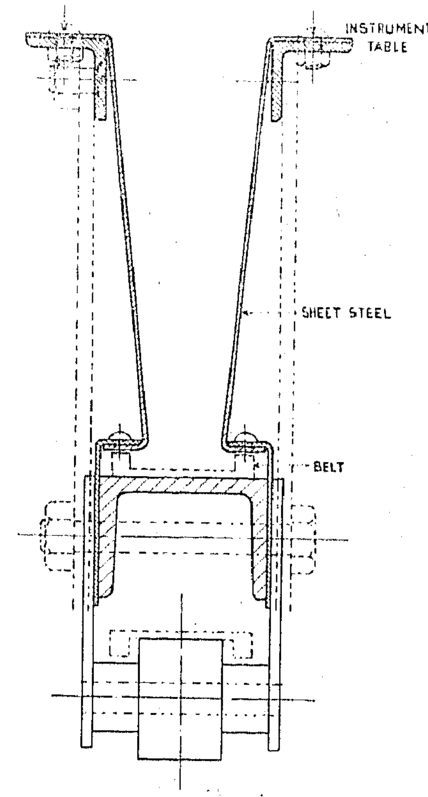

FIG. 22.—Sectional view of V conveyor.

for dispatch on teleprinter circuits are conveyed from the circulation table by hand, as the circuits are grouped in close proximity.

The introduction of the conveyors has resulted in a marked improvement as regards delay due to drag in the office. The maximum time occupied by messages in transit between a receiving point and the circulation

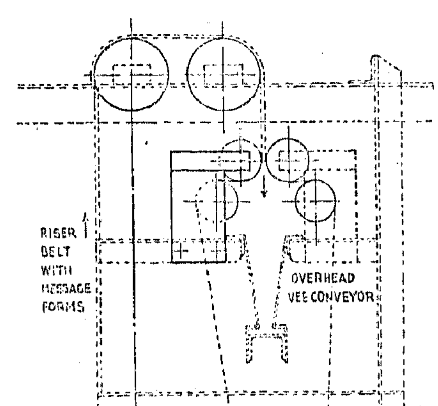

FIG. 23.—Overhead V conveyor with riser belt.

tables is 22 seconds, less than one-third of the average transit time when the duty was performed by perambulating girl probationers. The overhead conveyors have, however, been criticized for several reasons:—

(1) Observation of the traffic in the elevated trough presents difficulties.
(2) Shadows are cast on the instrument tables.
(3) The machinery is heavy and does not harmonize with other instrument room fittings.

In view of these objections further installations will dispense with the riser belt and overhead conveyor. The table V conveyor will discharge into a conveyor situated between the table and floor-levels.

Telephone-Telegram-Typewriter Circuits.

The teleprinter is provided for circuits carrying 150 or more messages a day, leaving a large number of smaller offices with a traffic load of 80 to 150 messages a day, which it is desirable to furnish with a typewriter key-board substitute for the Morse key and sounder.

In 1892 the Post Office introduced a form of concentrator switch for the telegraph service, somewhat similar to the telephone switchboards in use at that

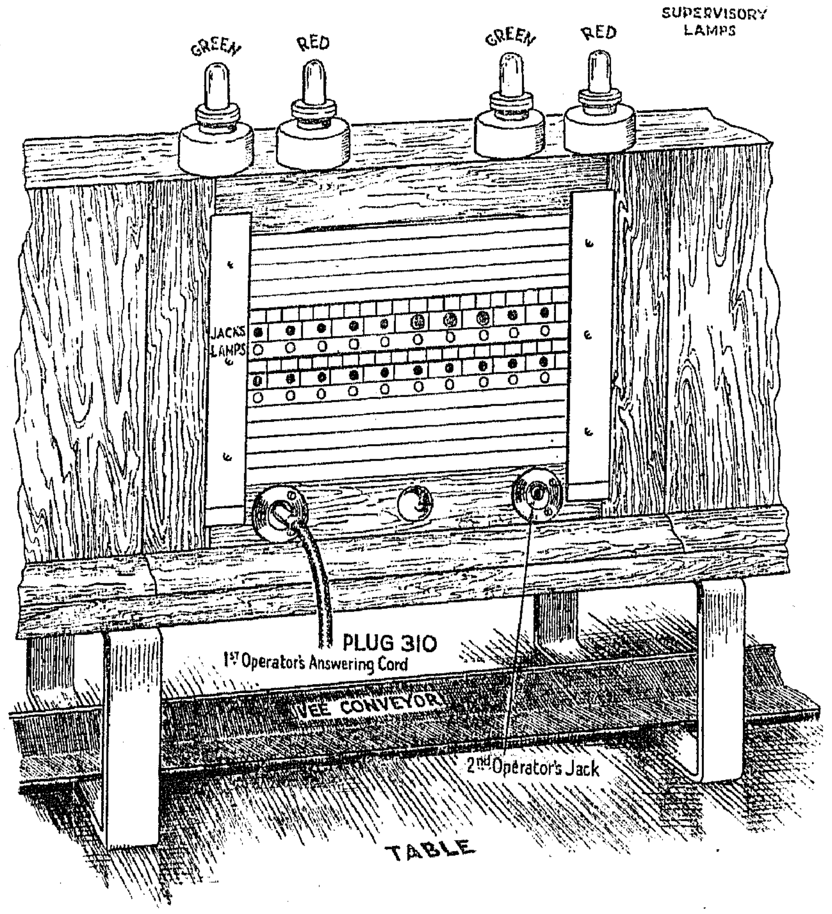

Fig. 24.—Telephone-telegram-typewriter circuits. Switchboard panels.

period, in order conveniently to group together offices not having sufficient traffic to justify the sole use of an apparatus set at the larger centre to which they transmitted their messages. Extensive use has been made of this system. The largest concentrators are designed to group 60 circuits, although the normal number accommodated is from 20 to 30. Each line terminates on a non-polarized relay which originates a lamp signal when an office on the line depresses the Morse key. The switchboard operator then extends the line to a Morse apparatus set by means of a plug and cord. The number of such sets, however, is only a percentage of the lines joined to the concentrator, hence there is a saving of space and apparatus. A central-battery system is usually employed, the Morse apparatus being worked by means of condenser impulses. In most cases offices connected to a concentrator are below the standard required for a teleprinter. Experiments have been made in the direction of typewriter reception on these circuits, a typewriter with a comparatively silent action being used to type the messages as they are dictated on the telephone. Where Post Office to Post Office is concerned the dictation of messages by telephone is free from certain difficulties met with when the general public is concerned. The officers at each end of the line are specially trained for the duty and, since they are in touch almost daily, peculiarities of articulation come to be understood. Results of the initial experiments have been sufficiently satisfactory to warrant the replacement of the telegraph concentrator at Leeds by four telephone-telegram-typewriter panels accommodating 17 line circuits.

Telegraph officials in the past have almost despaired of the introduction of typewriters as a means of dealing with telegraph traffic. Efforts have been made from time to time, but typewriter reception has never found favour with the staff in the British service. It would seem, however, that under present conditions reception by telephone can be linked with typewriter operation very satisfactorily, and it appears probable that the day of the concentrator system has come to an end. Machine telegraphy will displace the Morse apparatus even on minor circuits.

Telephone-telegram-typewriter panels.—Small switchboards, each having initial accommodation for 20 lines (Fig. 24), are mounted above the instrument table. At Leeds, double tables with a V-belt conveyor as already described are in use. Each switchboard has two operating positions provided with typewriters, a space of 2 ft. 9 in. being allotted to each operator. The lines are associated with calling lamps and jacks of a standard type. The operator's answering plug is employed to set up a circuit for two supervisory lamps mounted upon the switchboard. If a position is staffed the operator inserts one of the plugs of the answering cord circuit in a jack at the bottom of the switchboard. So long as one plug only is connected one of the supervisory lamps, coloured red, is lit. If now the operator answers a call by inserting the disengaged plug in a line jack the red lamp is extinguished and the second lamp, coloured green, is lit. The visual signals are for the information of an officer at a control position at one end of the suite. The messages to be forwarded from Leeds to the small offices connected to the switchboard are brought to this position. A control panel, similar in size to the switchboards, is fitted with two rows of press-buttons, each line circuit appearing on the ancillary panels having its particular press-button. Below the press-buttons are lamps, one for each operating position. So long as the position is staffed but not engaged the lamp glows; when engaged the lamp darkens.

The control officer determines whether an office for which a message is waiting is engaged by pressing the button associated with that particular line. If the line is engaged the lamp associated with the operator's position concerned glows. Should the line be disengaged the control officer can, at a glance, pick out a disengaged operator by means of the red lamps above the position or glowing lamps on the control panel. An amplifier is provided at each operating position, enabling the operator to regulate the degree of amplification of the received speech by means of a small rheostat.

The method of controlling the lamp signals is shown in Fig. 25. When the operator inserts a plug in the

operator's jack a 24-volt battery has a circuit via the red lamp, contact of relay A, springs 2 and 1 of jacks to earth. A second circuit is made via the position lamp on control panel, contact of relay A, springs 2 and 1 of jack to earth. To answer a call from line, the second plug of answering cord is inserted in the line jack. A circuit is now made from a 24-volt battery, coils of relay A, bush of jacks and sleeves of plugs, through 30-ohm resistance to earth. The operation of relay A disconnects the circuit of the red lamp and the position lamp and makes the circuit of the green lamp.

If the officer at the control panel wishes to ascertain whether a particular line is engaged at a panel, the

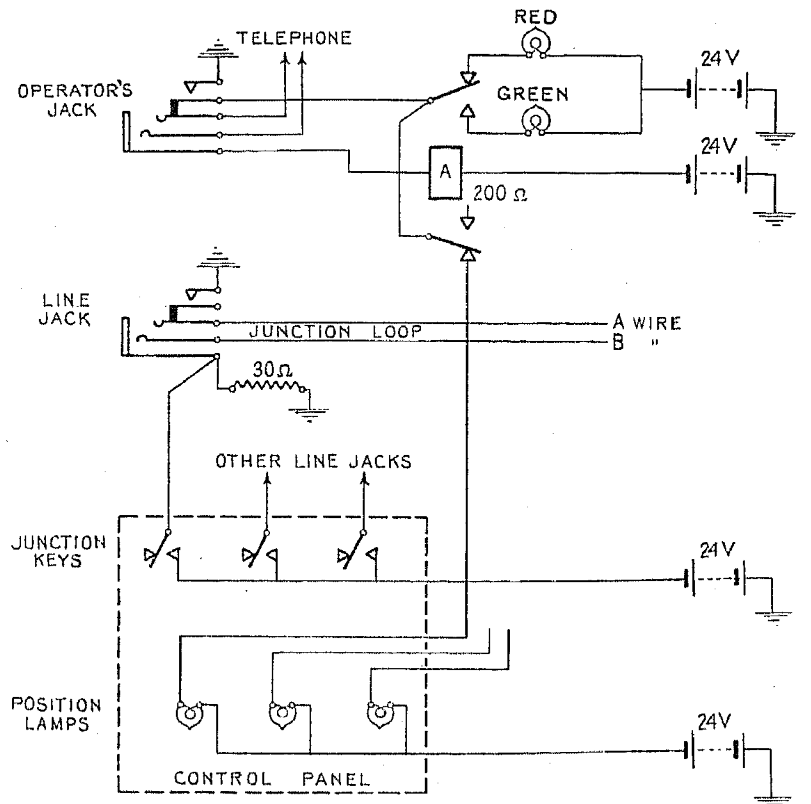

FIG. 25.—Supervisory lamp system.

relative junction key is closed, 24-volt negative batteries are now in opposition through relay A via the bush and sleeve connections, relay A releases so that a red lamp shows at the operator's position instead of green; also the position lamp on the control panel glows, 24 volts operating via the lamp, contact of relay A, and top springs of operator's jack.

The offices connected to the switchboard are called by means of a key at the operator's position which introduces generator ringing at 17 cycles per sec. After the calling lamps on the head office panels have been glowing for 15 seconds the steady glow changes to a flashing signal. It is probable that future installations of this type will form part of the phonogram suite in the phonogram room, instead of being housed separately in the telegraph instrument room.

PHONOGRAMS.

A telephone subscriber has the privilege of telephoning a telegram to an appointed Post Office for dispatch, and also of receiving telegrams from the Post Office by telephone. This arrangement is advantageous to both parties. The service is speeded up for the subscriber and the department is saved the cost of delivery, although in the case of a telegram delivered by telephone a confirmatory copy is forwarded by post. This class of traffic is known as "phonograms." There is a distinction between a "phonogram" and a "telephone-telegram." The latter designation applies to a telegram which has been transmitted between two Post Offices by telephone. The phonogram traffic is steadily growing in volume and accounts for 14·4 per cent of the total traffic; 4 800 telephones are employed solely for telegraph purposes. The service has been little more than half-sister to the telegraphs. Its parent is the telephone exchange, the operators are telephonists, and the apparatus is telephone plant. It seems probable, however, that a closer relationship with the telegraph instrument room will emerge. The duties of an operator in the phonogram room are not confined to switching; they partly resemble those of a Morse operator in that in both cases the function is auditory. Amalgamation

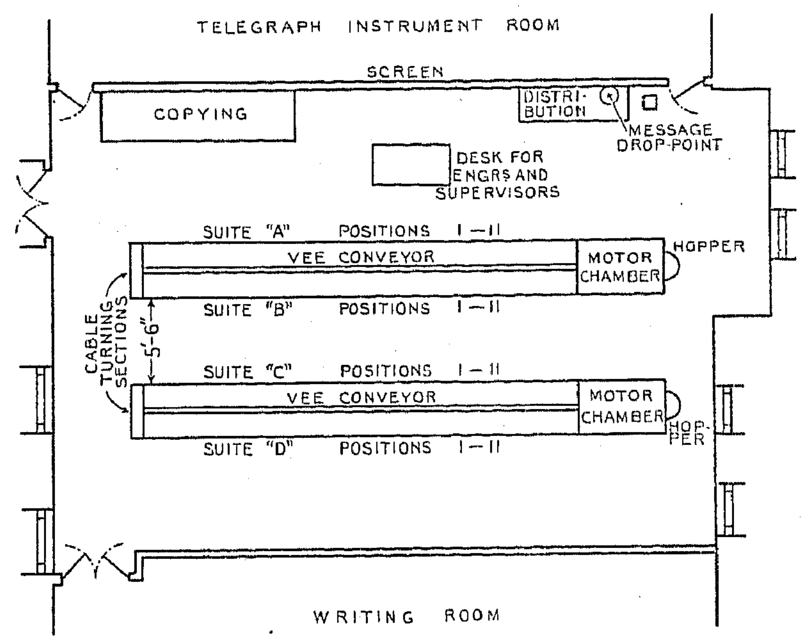

FIG. 26.—Lay-out of Leeds phonogram room. Scale $\frac{1}{16}$ in. = 1 ft.

of the staff and apparatus with the telegraphs is desirable for several reasons:—

(1) To save transit time between two separate rooms.
(2) To familiarize the staff with telegraph regulations.
(3) To maintain continuity of service with the same branch.
(4) To fill the growing need for typewriter experience.

Reorganization of telegraph instrument rooms will release a certain amount of floor space, which could be utilized for phonogram purposes. This course has been adopted at Leeds; the equipment of the phonogram room was obsolescent, its capacity exhausted, and further extension impracticable. The floor space given up by the telegraphs has been divided from the larger area by a screen and fitted with the latest-pattern phonogram apparatus. The lay-out of the phonogram room is shown in Fig. 26.

The standard equipment for phonogram rooms at large offices consists of "two-position continuous ancillary panels." Two operating positions face a series of 5 panels, each measuring 1 ft. 0 in. × $8\frac{3}{4}$ in.; these dimensions allow the two operators to make connections on either of the panels. The panels accommodate calling lamps, and jacks, in the circuit of lines

connected to the telephone exchange. All the lines available are multipled on each of the sets of 5 panels so that calls are spread over the whole of the operating staff. Each operator has on the left of her position a key shelf, which is equipped with two pairs of plugs and cords, with associated lamps in the cord circuit, three key-switches, an amplifier switch, a potentiometer to vary the degree of amplification, and a dialling unit. A plan of the panels is shown in Fig. 27.

The " two-position continuous ancillary panels " are installed at Leeds, but several novel features have been introduced. Double tables with V-belt conveyors similar to those in the telegraph instrument room are provided. The belt conveyor does not, however, deliver to a riser belt; instead, the message forms arrive at the circuit is materially reduced, thus providing a very rapid service from this country.

Lighting of Instrument Rooms.

The lighting of instrument rooms in large offices has always been a problem, and various methods of illumination have been tried. The avoidance of shadows is extremely difficult where the operating positions are fitted with apparatus rising above the writing-level; on the other hand, excessive candle-power gives rise to complaints of glare. From a general consideration of the new conditions of work at Leeds, it was evident that it would be necessary to place the lighting units in definite relation to the lay-out of the tables and teleprinter positions.

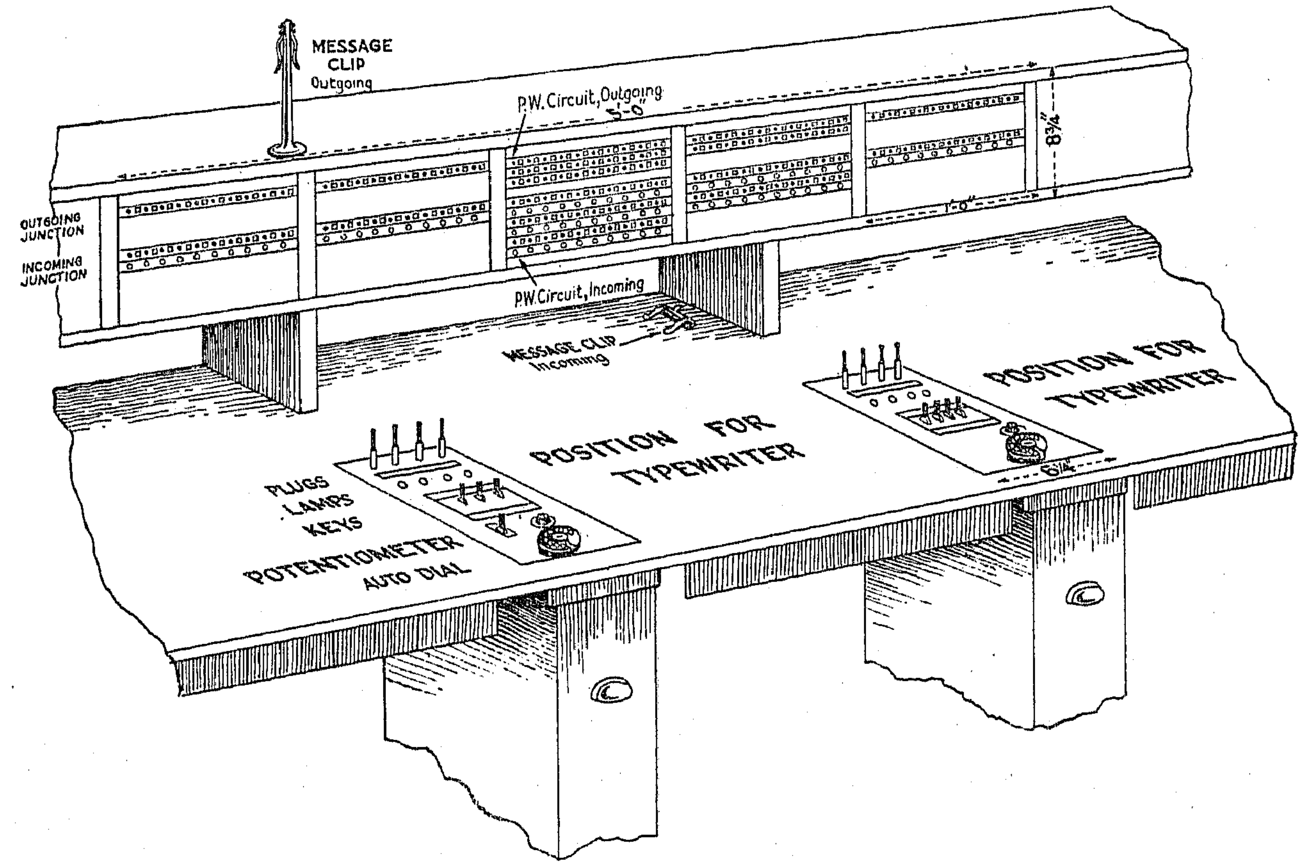

Fig. 27.—Phonogram circuits. Two-position, continuous, ancillary panels.

accumulate in a basket at the end of the table and are transferred to the circulation position by hand.

The panels have been mounted in two tiers to meet the requirements of double tables. The tiers face in opposite directions so that the operators on one side of the table make connections by means of the lower tier, whilst operators on the opposite side of the table use the upper tier. Development in the direction of typewriter reception being envisaged, standard tables 2 ft. 3 in. high are employed. The lower tier of panels is raised 6 in. above the table surface and situated above the opening to the V conveyor.

Initially, provision was made for 21 outgoing circuits, 39 incoming circuits, and 11 both-way circuits.

A rearrangement of the foreign section of the Central Telegraph Office has made it possible to establish a phonogram section in close proximity to the circuits serving France and the South of Europe. The equipment resembles that installed at Leeds except that double tables with V conveyor have not been introduced. The lapse of time between the receipt of a phonogram and its

Two methods were tried out on an experimental basis:—

(a) Units of suitable size were suspended over the centre of each double table.

(b) Similar units were suspended over the middle of the gangway between each two pairs of tables.

It was found that, while the intensity of illumination obtained in each case was practically the same, the gangway position was preferable as it avoided glare and sheen from the paper. The standard widths of the double tables and gangways being 3 ft. 8 in. and 5 ft. 0 in. respectively, the longitudinal spacing of the lighting units is 8 ft. 8 in., while the use of four units per row with 32-ft. long tables has resulted in a transverse spacing distance of 8 ft. As the lamps are placed inside the area formed by the tables, the maximum illumination is given to the working positions.

Semi-indirect units are used with 100-watt lamps in each, giving an intensity of approximately 4 to 5 foot-candles, under average conditions of working, in the

teleprinter section of the room. In the repeater section of the room and at the circulation and delivery positions, slightly different conditions obtain.

The instrument room has been redecorated throughout, all paintwork above the dado being ivory white; this assists the lighting effect and gives the room a bright and cheerful appearance.

Furniture.

Chairs for the use of teleprinter operators are designed in accordance with the latest medical recommendations for the prevention of physical fatigue and discomfort. The seat is adjustable in height, and the back rest is adjustable in height and also laterally. Both the seat and the back rest are padded, shaped, and dished to give the maximum degree of comfort and support, and it is satisfactory to be able to record that the staff consider these chairs " extremely comfortable."

Tables.—Two standard instrument tables are in use, one for general purposes, the other where typewriter keyboards are installed. The top of the general table is 2 ft. 6 in. above the floor-level, and is 2 ft. 3 in. wide; it is made of birch wood having a cork carpet 6·7 mm thick glued to the upper side, and the surface of the cork is varnished. The table accommodating keyboard instruments is 2 ft. 3 in. high and 2 ft. 0 in. wide, similarly furnished as regards the table top. Where double tables are installed, as at Leeds, the width is reduced to 1 ft. 9 in. The woodwork is carried on cast-iron standards in every instance. These tables replace the substantial and expensive mahogany-top type that has been in use for many years. The change has one drawback in that the varnished surface tends to become sticky under certain atmospheric conditions.

As an alternative to the cork carpet a covering of dark green " Ruboleum " is being supplied and is considered to be an improvement.

Several small details of instrument-room management, not of particular interest to electrical engineers, may nevertheless be of general interest. In the heyday of Wheatstone working a telegraph instrument room presented a very untidy appearance. The paper tape waiting to be transcribed hung about in festoons, and after transcription it was thrown to the floor. Messengers were employed to go round at intervals, with rubber scrapers, to clear the floor (and incidentally raise the dust). A multiplicity of forms and rolls of paper littered the tables, and small confetti from the perforating instruments drifted everywhere. Needless to say, this state of affairs was an annoyance to all parties. The modern instrument room will be beyond reproach as regards tidiness. Metal waste-paper bins are provided at each teleprinter position, receptacles for forms are conveniently placed below the instrument table; and hooks for the ladies' handbags are fixed beneath the table at the operators' positions. The instrument rooms are sprayed two or three times each day by means of a vaporizer, the fluid varying according to local preference. At Leeds a preparation sold under the name of " Kilkrobe " is used, whereas in London a mixture made by dissolving a small quantity of Lysol crystals in a gallon of water is preferred.

One perennial source of controversy awaits an acceptable solution—heating and ventilation. It appears

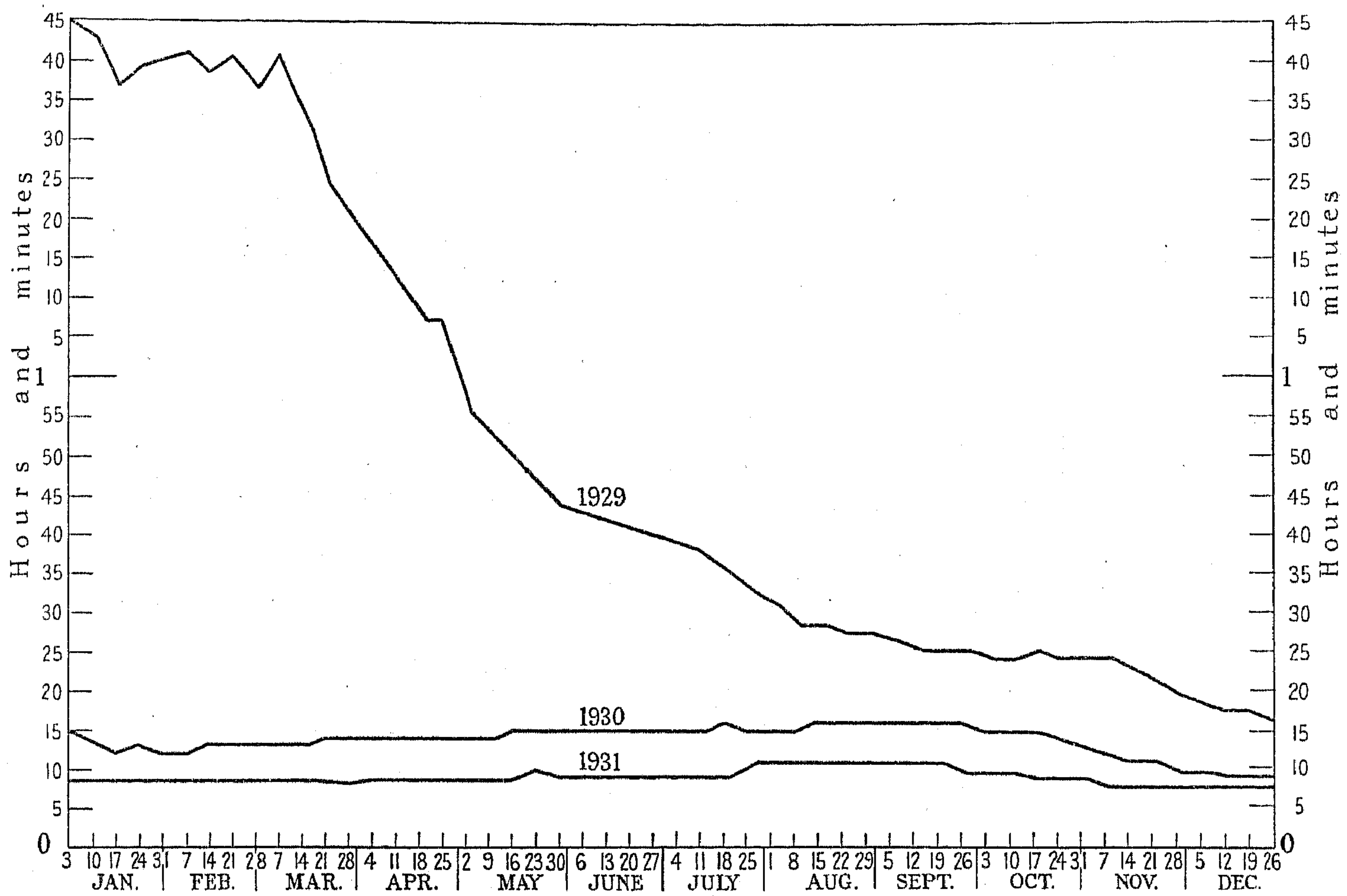

Fig. 28.—Stability chart of teleprinter circuits.

impossible to regulate the atmosphere so that it is equally congenial to the young and the elderly, the robust and the delicate, the normal and the faddist. The "windows" are not the least of the troubles of a supervising officer.

The question may be asked: "What is the effect of the new machinery and methods that have been described?" It is, of course, too early to pass judgment in this matter. The programme of development is still far from complete, but such periodic returns as are available clearly indicate a tendency towards improvement in several directions.

(1) There is progressive gain as regards circuit stability. The increasing percentage of circuits routed on underground conductors reduces the number of stoppages due to climatic conditions.

(2) The value of the technical education of the staff during the last three years is reflected in the striking reduction of the average time lost per circuit due to causes other than line or power supplies. The chart in Fig. 28 shows that the average time lost per week on teleprinter circuits is 8 minutes.

(3) The teleprinter, where it has replaced Morse working, has eliminated a class of errors inherent in manual transmission by Morse code. Malformation of the signals at the sending end and a tendency to "guess" at the receiving end of a circuit are faults difficult to eradicate; they have been responsible for a small but steady stream of complaints in the past. The teleprinter operator is not infallible. The possibility of a mistouch or wrong letter remains, but such mistakes are usually obvious at the receiving end. With a view to the detection of faulty manipulation a system of observation has been introduced. At a convenient position in the instrument room arrangements are made to produce a local record of the signals being transmitted on any particular teleprinter circuit in the office. The work of each operator is under test periodically and, should errors occur which are obviously due to a faulty style of manipulation, useful advice is given and, if necessary, further training.

The number of complaints received from the public during April 1931, as compared with April 1929, a period under review, showed a striking diminution.

(4) There is a slight increase in the average operator output, taking the whole operating staff and all classes of instruments as the basis of comparison between 1929 and 1931.

Advantages of the New System.

The advantages arising from the rearrangement of instrument rooms as demonstrated by the Leeds experiment may be summed up as follows:—

From an engineering standpoint:—

(1) Economy of space. The same number of circuits may be accommodated in a smaller area owing to the use of double tables.

(2) Economy of apparatus, e.g. only one Morse key and sounder is required for each group of eight teleprinter circuits.

(3) Rapid and accurate localization of faults on the instrument side, by means of the interpolation of jacks in each instrument lead.

(4) Concentration of the testing of lines, instruments, and batteries at one point.

(5) The wiring at instrument tables is reduced to a minimum.

(6) Engineering work can be carried out without interference with the traffic staff.

(7) Facilities exist for observing the signals in both directions.

(8) Reduced risk of faults arising from wires making bad connection with screw terminals, or being broken at the tables.

(9) Facilities for testing and grading relays and teleprinters.

From the commercial standpoint there are also numerous advantages:—

(1) Extreme flexibility of the concentrator system.
(2) Supervising officers freed from technical duties.
(3) Staff economies.
(4) Reduced office transit delay.
(5) Less congestion, owing to abolition of collectors.
(6) Costly extension of premises avoided by releasing part of the instrument room for other purposes.

Teleprinter Service for Subscribers to the Public Telephone System.

In a paper read before the Institution in October 1924, Mr. Donald Murray, forecasting the development of the telegraph service in the direction of teleprinter working, visualized a mechanized service and the creation of teletype exchanges, referring particularly to a big central teletype exchange at the Central Telegraph Office, London. A substantial part of the vision has materialized; the telegraph service is dominated by the teleprinter and telegraph typewriter. The exchange service predicted is on the threshold of realization, although not exactly in the form anticipated. The creation of a separate system of exchanges for the exclusive purpose of linking up subscribers to a telegraph exchange service was carefully considered, and it became apparent that such exchanges would be slow to provide an effective service, whereas the use of the telephone network gives a nation-wide service without the delays incidental to building up a separate teleprinter exchange system. Exhaustive trials proved that a service could be provided over the existing telephone lines, both local and trunk, without alteration of the existing telephone exchange plant, and that an alternative service, telephone or telegraph, was quite practicable. A system on these lines has been adopted and a telegraph exchange service operated by teleprinters is about to be offered to subscribers in any part of the country having the telephone service available.

A subscriber to the telephone service may obtain, in addition, the telegraph exchange service on payment of an additional rental to cover the provision and maintenance of a teleprinter and other necessary apparatus. Communication, either by speech or by teleprinter, is available at the telephone call tariff, local or trunk, between telephone subscribers who rent teleprinters and the associated apparatus. The calls originate to and from the subscribers in the normal manner through the local telephone exchange. Subscribers who so desire may also rent an auxiliary unit which enables the

teleprinter to receive messages during their absence. That is to say, their teleprinter will be open for business 24 hours a day although the staff keep the normal City hours.

A teleprinter service without alternative speech facilities, at a lower tariff on certain long-distance routes at specified centres, is a probable development at an early date. Renters of a private wire circuit, for instance firms who rent a circuit between two given points for their exclusive use, will be able to take advantage of the wider field by renting the auxiliary apparatus associated with the exchange service. They may, however, in certain circumstances also be required to rent an additional exchange line at the normal telephone tariff. Subscribers to the new service will be able to pass telegrams to the Post Office for transmission to other centres, speeding up the transmission time, and to receive incoming messages at their office by using the word "Telex" in the address of the message. The actual transit time of messages between telegraph centres is so small that under the conditions of the new service the telegraph will offer a service as rapid as the telephone.

The telegraph will now obtain a footing in territory held exclusively, hitherto, by the telephone, since a teleprinter may be installed in the home, office, or factory of any member of the community. The instrument will enable printed communication, in either direction, to be made at a maximum speed of 66 words per minute. The actual speed obtained will of course depend upon the operator's skill in manipulating the typewriter keyboard of the teleprinter. The new partner should be an ally, not a competitor in the business. Certain messages are of such a nature that transmission by speech involves a risk. Figure and code messages are, at times, difficult to pass telephonically, whereas the teleprinter, which has the virtue of being unable to guess, would experience no difficulty. The human factor is ruled out. The demand for telegraph facilities for private circuits has frequently been in excess of the plant available, and it is anticipated that the new service will meet a long-standing public need.

Apparatus.

The teleprinter employed for the exchange service, known as No. 7A, in general appearance resembles the machine in use for public service; with cover in position it measures $23\frac{1}{2}$ in. wide, $23\frac{1}{2}$ in. deep, and 13 in. high. The total weight is 61 lb. The machine has several new features, additional parts being provided to fulfil functions not required of machines employed in telegraph offices:—

(1) By means of alternative attachments the messages may be received printed in page form or on a continuous tape.

(2) An automatic starting switch operated by the first signal received from the line closes the motor circuit of the machine and, if signals are not received during a period of two minutes, breaks the motor circuit. The machine therefore is not running continuously, so that maintenance costs are reduced.

(3) During transmission of a message, if the sender desires to confirm that it is being received, by operating a particular key (the letter J) a bell at the receiving end is actuated. This facility allows the receiving clerk to proceed with other duties whilst the teleprinter is working, the bell signal being an indication that attention is required.

(4) Identity signal. The sender of a message may be desirous of verifying the telephone connection, to make sure that a "wrong number" has not been given, and for this purpose each machine is provided with a "Who are you" key on the keyboard. The signal sent out by means of this key releases an "answer-back" drum on the distant teleprinter. The barrel of the drum has wards corresponding to the telegraphic code for the exchange and subscriber's number of the renter. The release of the drum transmits, automatically, the exchange and number in answer to the "Who are you" signal. With these precautions, the risk of a message being sent to the wrong station may be regarded as negligible.

(5) A lever on the machine throws out the paper feed should a continuous spacing current be received or the electrical contacts develop a spacing bias, thus preventing waste of paper or tape.

The sequence of operations between two subscribers is as follows:—A subscriber wishing to communicate calls up the local exchange, manual or automatic, and is put through to the number required. Upon gaining attention at the distant end a request is made "put me to teleprinter." The called subscriber responds by turning a switch, which also starts up the teleprinter. The first subscriber starts his machine by pressing a button and operates the "Who are you" key. The identity, signalled back, is printed on the message form, followed by the communication which is now transmitted, and printed at both ends simultaneously. There is, therefore, a file copy of every transaction, prefaced by the telephone number of the subscriber to whom it is sent. Absolute secrecy of service is assured, since the operators at the telephone exchange are not in a position to translate the teleprinter signals passing through the exchange equipment.

The teleprinter signals are transmitted to line as single-tone voice-frequency currents by means of a convertor unit. The necessary apparatus is enclosed in a small cabinet $16\frac{1}{2}$ in. wide, $10\frac{1}{2}$ in. deep, and $8\frac{1}{2}$ in. high, suitable for mounting on either a table or a wall. Four 3-electrode valves are employed for the convertor, viz. an oscillator valve, a rectifier valve, and two amplifier valves. The operation of the valve set is given below:—

Reception.

When the teleprinter is in a "receive" position, having its contact tongue on the marking stop, incoming voice-frequency currents from the telephone loop (Fig. 29) are coupled through the line transformer, T48H, to the primary of an input transformer, T56A. From the secondary of this transformer the signals pass to the grid of the rectifier valve via the grid leak and condenser. The alternating current is rectified by the action of the valve which results in an increase of current in the anode circuit. Transformer No. 57A in the anode circuit of this valve has a secondary winding in two parts. The rise of current in the primary winding induces a

momentary current in the secondaries, which are each connected directly to the grid of an amplifying valve. It will be noticed in Fig. 29 that the anodes of the two amplifying valves are connected to opposite sides of the teleprinter electromagnet and that the centre point is connected to the H.T. supply. The momentary current causes the grid of one of the valves to become positive, increasing the anode current and moving the armature of the teleprinter electromagnet since it forms part of the anode circuit. The grid of the second valve is made more negative by the momentary current referred to, hence no change takes place in the anode current. On the cessation of the signal, the fall of current in the anode circuit of the rectifier valve creates a pulse in the secondaries of transformer 57A in the opposite direction rectifier valve and results in a local record of the message transmitted.

It is necessary to provide for either a.c. or d.c. working of the local apparatus to meet the electricity supply conditions at the various subscribers' premises. The need is met by two power panels, panel No. 1 for a.c. supplies, and panel No. 2 for d.c. supplies. The arrangement of panel No. 1 is shown at the right-hand side of Fig. 29. The a.c. supply is connected to the primary of a transformer having its secondary winding divided into three parts. The upper part, F1, supplies current to the filaments of the rectifier and amplifying valves. The winding F2 supplies current for the oscillator valve. The output of the third winding is rectified, passed through a smoothing filter, and fed to the anode of each

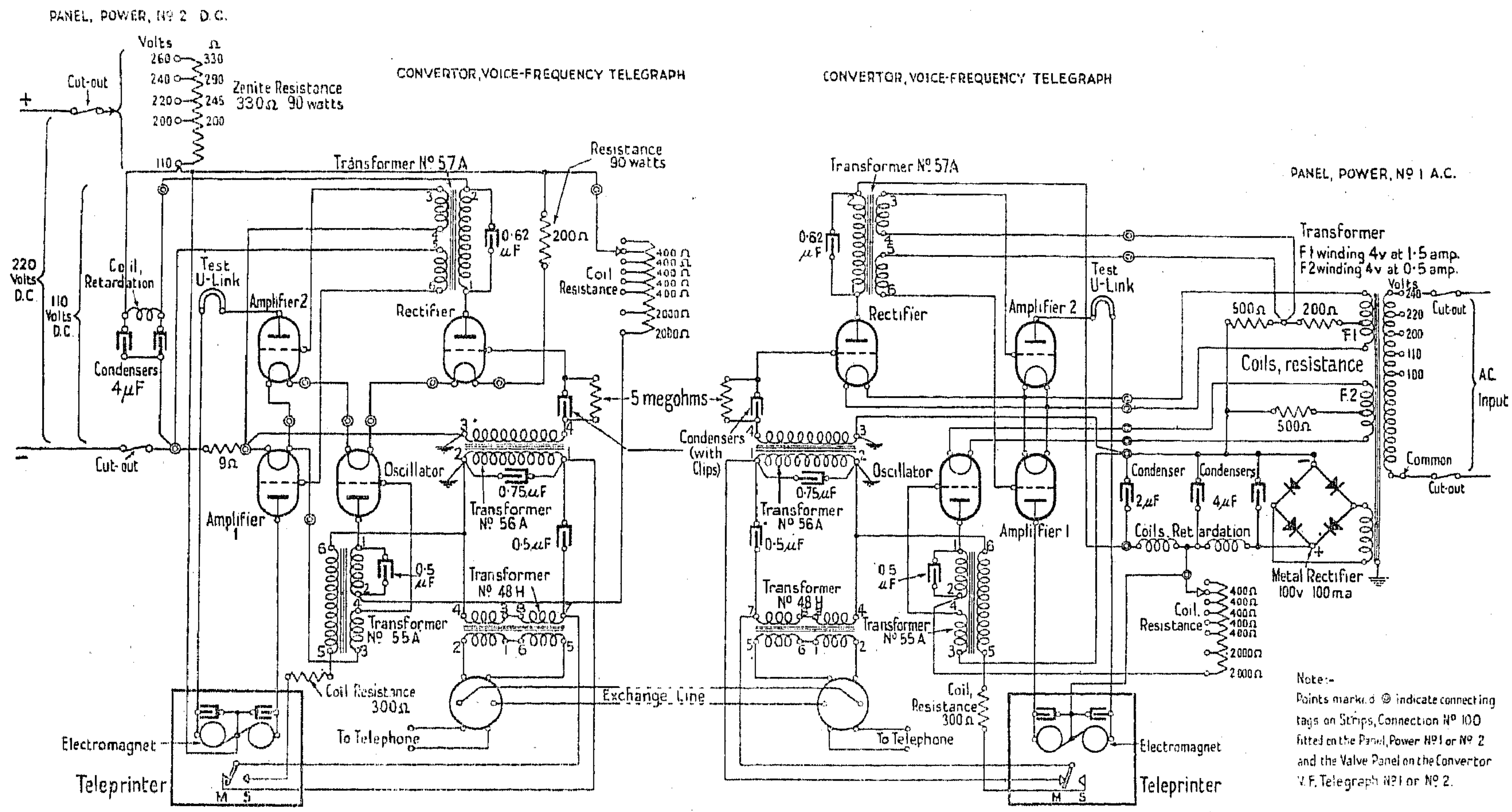

FIG. 29.—Teleprinter exchange service, convertor unit.

to that described. The potentials of the grids of the amplifier valves are now reversed, with the result that a current flows through the second limb of the teleprinter electromagnet, moving the armature back to normal. The two valves constitute a push-pull arrangement equivalent to double-current working. The condensers connected across the coils of the teleprinter electromagnet assist this action.

Transmission.

The tuned anode circuit of the oscillator valve is coupled to the grid circuit, to produce self-oscillation, by Transformer No. 55A. The output of the transformer, at the oscillation frequency of 300 cycles per sec., is connected to another transformer (48H) and, when the line circuit is closed by the teleprinter tongue moving to contact S, passes out to the telephone loop. Simultaneously a portion of the output of the oscillator valve is diverted via the $0\cdot5$-μF condenser to transformer 56A. This portion of the current passes to the of the four valves. The grid of the oscillator valve is connected to the H.T. negative and also to the centre point of F2, through a biasing resistance of 500 ohms. The grid of the rectifier valve is connected to the H.T. negative, and to the centre point of F1, through resistances of 500 ohms and 200 ohms in series. The 200 ohms is in the path of the grid return to F1 of the two amplifying valves, and the 500 ohms is in the path to the H.T. negative.

The arrangement of panel No. 2 is shown at the left-hand side of Fig. 29. In this case the positive of the d.c. supply is obtained via an appropriate adjusting resistance, and passed through a 200-ohm tenite resistance to the filaments of the four valves in series. A biasing resistance of 9 ohms is included in the return to the H.T. negative. The grid of the oscillator valve is connected to the positive side of the filament of the last valve of the series. The grid of the rectifier valve is connected to the H.T. negative via the 9 ohms biasing resistance in the filament common return. This arrange-

ment is a means of obtaining the correct bias for each of the valves.

Private-Wire Telegraphs.

The number of by-product channels of the main telephone cables, providing telegraph circuits of Types 7 and 8 (Fig. 3) is, generally speaking, in excess of the number likely to be required for the public service. These channels are not suitable for speech transmission, but may be utilized by any system of telegraphy having a line speed of 40 cycles per sec. or less (100 words per minute). There is reason to suppose that a potential demand for private-wire circuits within this speed limit exists and could be made a source of revenue by leasing channels on a rental basis. The whole question of private telegraph and telephone circuits was reviewed by a Post Office Committee who, early in 1931, issued a report recommending that certain additional facilities for communication should be offered to the public. Consequent upon this report, channels of communication for the following private-wire services may now be obtained under an agreement with the Postmaster-General. The first two services, where plant is available, will be provided by means of by-product channels.

(1) Teleprinter simplex service. This service is offered on attractive terms which include the provision and maintenance by the Post Office of teleprinters of the type mentioned in the preceding section. A simplex circuit implies that communication can be made from either end of the circuit in turn but not from the two ends simultaneously.

(2) Telegraph low-speed service. Under the conditions of this service the channel may be worked either simplex or duplex by means of apparatus provided by the renter or obtained from the Post Office. The service could be utilized for Morse, Wheatstone (not exceeding 40 cycles per sec.), or multiplex working.

(3) Telegraph high-speed service. An increasing demand for channels suitable for high-speed telegraph working is made by newspaper companies and Press agencies who transmit from London to their provincial centres. The circuits are usually worked by Wheatstone apparatus, using Creed receivers and perforators. In many cases one main channel from London serves a number of centres by means of leak circuits teed off at suitable points. The channels offered under this service are capable of a line-speed of not less than 80 cycles per sec. (200 words per minute).

(4) Private telephone service.

(5) Private high-grade facsimile, or music, transmission service. Where such channels are available they are capable of a line speed of not less than 2 400 cycles per sec.

Line terminal apparatus and circuit connections to meet the new conditions are being devised but involve nothing new to telegraph science.

Conclusion.

Development in the Inland Telegraph Service has proceeded with such rapidity since the autumn of 1930 that the author has found difficulty in describing minor details of the equipment owing to uncertainty as to the exact final form. It may be taken, however, that the main features of the reorganization of the service prior to April 1932 have been included. The author desires to acknowledge the assistance given by the staff of the Superintending Engineer of the North-Eastern Engineering District, Mr. J. W. Atkinson, in respect of the Leeds Office, and to the members of the Traffic Section of the Secretary's Office, London, for statistics and other details of inland telegraph traffic.

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(Appendices 1 and 2 will be found on pages 218 and 220 respectively.)

APPENDIX 1.

Commission of Inquiry into the Organization and Methods of the American Telegraph Companies.

Recommendations.

I.

(*a*) *Apparatus.*

(1) Multiplex working should be replaced by teleprinter working on all routes on which it is possible and economical, by means of compositing or voice frequency to provide the requisite number of separate channels. On such multiplex circuits as are retained the channel speed should be not less than 50 words per minute, and type-keyboard and tape-printing apparatus, capable of working at not less than 60 words a minute, should be universal. The number of arms should not normally exceed three.

(2) On automatic multiplex and teleprinter routes a considerably higher output than that on which the existing staffing standards are based should be required (*see also* 24 below).

(3) The process of converting Morse circuits to teleprinter or telephone working should be carried further than has hitherto been contemplated. As a first step, every Morse circuit carrying as many as 200 messages a day at any time of the year should be scheduled for conversion to teleprinter working at the earliest possible date. Concentrator working with teleprinters should also be adopted as soon as practicable.

(4) A uniform type-keyboard should be adopted for all multiplex and teleprinter circuits in the inland service. All other types of keyboard should be replaced by the standard type as rapidly as possible.

(5) Adequate reserve apparatus should be provided at every office at which printing telegraph instruments are used. Morse and Wheatstone should cease to be regarded as stand-by apparatus for emergencies.

(6) The use of Wheatstone apparatus, whether for emergency purposes or for Press work, should be abandoned as soon as possible.

(7) Reception on all Morse and telephone circuits should be by typewriter at the larger offices, and Wheatstone slip should be transcribed by typewriter where Creed apparatus is not in use.

(8) Electrically operated timing stamps should be fitted at the receiving positions on multiplex circuits and the principal teleprinter circuits.

(*b*) *Lay-out.*

(9) Double tables with V-belt conveyors should normally be provided in the larger instrument rooms; and whenever the phonogram equipment at a large office has to be replaced, the question of installing four-position panels, with two positions on each side of a double table with a belt conveyor, should be considered.

(10) The present type of circulation table should be abandoned at the largest offices, and the moving-belt system in use at New York, Chicago, etc., should be introduced.

(11) All apparatus other than that actually required by the operators to enable them to dispose of telegrams should be removed from the instrument tables and accommodated in test rooms or other suitable positions. An exception should be made only in the case of multiplex distributors.

(12) All circuits worked by apparatus of the same type (multiplex, teleprinter, Morse, Wheatstone) should be grouped together as far as possible.

(*c*) *Maintenance.*

(13) Responsibility for the efficient working of circuits and for the control, adjustment, and day-to-day maintenance of apparatus should be definitely vested in the traffic officers in charge of instrument rooms.

(14) All testing, regulating, and maintenance work in the larger instrument rooms should be allotted to officers selected from the operating staff, who must possess the necessary technical knowledge and skill, and should receive an appropriate special allowance. The departmental technical examination, suitably revised, should serve as a qualifying test for these officers, and a scheme of training should be drawn up for those who qualify. The selected officers should normally be relieved of operating duties, but should be liable to be called on to perform them in case of need.

(15) The technical allowance, the additional increment granted to holders of the present departmental technical certificate, and the allowance to dirigeurs (who would disappear under recommendation 14), should be abolished (subject in the case of the two former to the rights of existing holders).

(16) At the smaller offices the day-to-day maintenance should be carried out by the operators (*see* recommendation 22), subject to periodical inspection by engineering staff.

(17) A life history of each apparatus unit, including a record of faults, adjustments, and periodical overhauls, should be kept at every office.

(*d*) *Recruitment, Training, etc.*

(18) The number of offices at which sorting-office and instrument-room duties are performed by a common staff should be reduced to a minimum.

(19) At any office at which it is found possible to employ a separate staff for telegraph work, new female entrants on the telegraph side, other than those who will be required to do Morse work, should wherever possible specialize in one of two groups of instrument-room duties: (1) Printing telegraph and phonogram work, and (2) non-operating duties (excluding clerical work). The latter group of duties should be withdrawn gradually from the operating staff. Each new female entrant should receive only the training necessary for the group of duties on which she will be employed.

(20) No new entrant should be recruited for keyboard operating and phonogram work who is unable to pass prescribed digital, auditory, and other tests.

(21) In order to ensure an adequate supply of male telegraphists who will be able to qualify for testing and regulating duties, the recruitment of male telegraphists by open competition should be resumed, a certain number of places remaining open to boy messengers, who should be required to pass a limited competition.

(22) The training of keyboard operators should be revised and improved, and the qualifying standard should be raised. In the case of operators at small offices with teleprinter circuits, the training should include instruction in the day-to-day maintenance of teleprinters.

(23) So far as possible each operator should specialize on a particular type of apparatus—Morse, teleprinter, multiplex, or telephone—and training in Morse working should be confined to operators (including all male operators) who will be employed on Morse circuits. Rotation should be reduced to a minimum, and changes of duty should be allowed only between officers of approximately equal qualifications.

(24) So far as possible the most expert operators should be assigned to the most heavily loaded routes, both multiplex and teleprinter, and a special allowance should be granted for the higher output which should normally be obtained on those routes.

(25) Operators employed on duplex channels should send and receive alternately for periods of two hours.

(26) In addition to the authorized meal reliefs, two regular rest reliefs of 15 minutes each should be allowed on any continuous duty of eight hours or more, and one on any continuous duty of less than eight hours. At the Central Telegraph Office, however, where the dinner relief is at present three-quarters of an hour, the dinner relief and rest reliefs should not exceed one hour in all on a duty of eight hours or less.

(27) Casual reliefs should be strictly limited to cases of real urgency.

(28) At the larger offices a time card should be used by each operator.

(*e*) *Supervision and Control.*

(29) In view of the greater concentration of traffic on channels working at high speeds, the size of supervising areas should be reduced in order to secure keener supervision and a higher output; it being understood that in future a more rigorous standard will be applied in the filling of supervising posts and promotion will be restricted to officers who are qualified to give fully effective supervision.

(30) The male supervising grades in instrument rooms should normally be recruited from the testing and regulating staff.

(31) A monitorial scheme should be introduced with a view to the detection and prevention of operating errors.

(32) A daily record of output at each circuit should be maintained, and these records should be carefully scrutinized by the responsible local officers, who should take suitable action wherever a low output is disclosed.

(33) A system of centralized supervision of the disposal of traffic over the principal routes should be introduced if the limited experiment already inaugurated proves successful.

(*f*) *Press Work.*

(34) Newspapers should be offered the facility of having special wires led into their offices for the direct receipt of reports of race meetings and other special events, the Post Office providing wires, teleprinter, or Morse apparatus, and operators for short periods on suitable terms.

(*g*) *Delivery.*

(35) In no case should a telegram for an address in a business area wait at the delivery stage for more than 5 minutes during the normal hours of business.

(36) Boy messengers should be paid on the basis of distance covered, subject to a fixed minimum according to age, the walks being arranged so as to afford all the boys at an office as nearly as possible equal opportunities of adding to their earnings by increased effort.

II.

(37) Attractive leaflets or "folders" setting forth the usefulness of the telegraph system for speedy communication (both at home and abroad) should be available at Post Offices, and so far as possible in hotels, railway stations, etc. They should also be sent to telephone subscribers with their accounts from time to time, and should be distributed from house to house in suitable localities. They should be as unofficial as possible in style, and should aim in particular at dispelling the popular idea that a telegram always brings bad news.

(38) The equipment of the larger public offices should include—in place of or in addition to the existing message

stalls—a special glass-topped table, with chairs, for writing telegrams. The table should display the sign " Write your telegrams here " in attractive type and colour, and should be kept furnished with the different types of telegram forms and with serviceable pencils.

(39) The quality of the delivery forms and envelopes should be improved.

(40) The positions of telegraph offices should be more widely indicated by street signs, preferably illuminated.

(41) The facility of summoning a messenger by telephone to collect a telegram (inland or foreign) should be afforded in business districts and in developed residential areas.

(42) Large users of the inland telegraph service—in the first place holders of deposit accounts—should be visited periodically by canvassers, who should inquire as to any cause of dissatisfaction or as to the reason for diminished use of the service, and should make it clear that the Post Office is anxious to maintain contact with its customers and to satisfy their requirements.

(43) Large users should be given the name and telephone number of an officer at the local Head Office—where possible a canvasser—with whom to communicate in any case of difficulty or dissatisfaction.

(44) The convenience of the telephone for sending and receiving telegrams should be stressed by canvassers and by means of small adhesive labels attached to delivered telegram forms. The Night Telegraph Letter service should be similarly advertised where this facility is afforded.

(45) Special delivery forms and envelopes for telegrams conveying greetings at Christmas, Easter, birthdays, etc., should be designed, and appropriate formulæ for these occasions should be suggested (though not insisted on). These telegrams should be subject to the ordinary tariff and treatment.

January 1929.

APPENDIX 2.

Syllabus of Training Course for Candidates for the Testing and Maintenance Staff.

Section 1.
- (*a*) Test boards, panel-mounted apparatus. Testing instruments and testing apparatus. Power supply.
- (*b*) Morse apparatus, adjustments.
- (*c*) Balancing of duplex circuits. Repeaters.
- (*d*) Typewriters, cleaning and adjustment.
- (*e*) Gumming equipment.

Section 2. Teleprinters.
- (*a*) Mechanism.
- (*b*) Circuit connections.
- (*c*) Adjustments.
- (*d*) Faults.

Section 3.
- (*a*) Methods of superimposing telegraph circuits.
- (*b*) Composited and phantom circuits.
- (*c*) Voice-frequency circuits, filters.

Section 4. Baudot multiplex.

(For students from offices working this system.)
- (*a*) Cleaning and adjustment.
- (*b*) Morning overhaul.
- (*c*) Testing, governors, moderators, perforators, transmitters, receivers, and distributors.
- (*d*) Three-station working, re-transmitters.

Discussion before The Institution, 17th November, 1932.

Mr. H. H. Harrison: None of the apparatus or methods of arrangement described in the paper are broadly new. The segregation of apparatus other than that actually used for reception and transmission is a very old practice in America. I am glad to see that the differential galvanometer has been superseded by the milliammeter. I should like to refer to the method I saw in use at Leeds, and which I presume is now standard with the Post Office, of using a rotary switch for withdrawing or inserting capacity more or less continuously in small steps. I think I was the first to propose this idea in connection with panel mounting equipment, but the Post Office method of solving the problem is much neater and cheaper than my own. The mechanical collection and distribution of messages in large instrument rooms is now common in most telegraph administrations. It has always been a puzzle to me why the Post Office have not previously replaced batteries by dynamos. When I was in the United States I visited several of the large telegraph offices,

and the compactness and neatness of the dynamo as compared with the battery plant struck me very much. Referring to the paper generally, we have discarded what I would call the "clock-maker cabinet-maker" type of design, and the fact that our apparatus and its arrangement now seem to draw their inspiration rather more from the engineer is a matter for congratulation. With regard to the operating figures, how were the figures for man-hours with the various systems obtained? Are they, for instance, a general average taken over a large number of circuits handling varying classes of traffic, or was any allowance made for the variations in traffic, e.g. between London and a shipping centre, and London and a seaside town in the holiday season? I should like to know whether a receiving and a sending operator are provided on a duplex teleprinter, or whether it is a one-man or one-woman system. I think the sustained speed of 300 to 400 words per minute credited to the Wheatstone transmitter is an over-estimate, and, further, the received slip would be very troublesome to handle at such a speed. I am sufficiently optimistic to believe that there is a great future for the modern systems of telegraphy described in the paper, and I am sure that many large provincial firms having big London connections would find it an economy to adopt the Telex system.

Col. Sir Thomas F. Purves: The paper describes the most sweeping change that has ever been applied to the public telegraph system of this country since the art of electrical communications first took shape. Although the telegraph service has a long and rather melancholy record of annual deficits behind it, the Post Office did not hesitate to spend a great deal in the re-equipment of the system as soon as it became evident that improved operating conditions could be obtained that would represent long-range economy in annual charges. That the progress of machine telegraphy in this country has been slow is due entirely to the fact that none of the many new systems which have been tried have proved capable of beating the Morse system, which has been more fully developed and exploited by the British Post Office than by any other administration. It has now been beaten by the teleprinter, a comparatively simple, robust, and cheap machine, admirably adapted to utilize the by-product circuits which can now be obtained from the telephone system at very little cost and without reducing either the number or the efficiency of the telephone channels. As long as the telegraph system of this country has to serve a large proportion of rural and small-town districts it can only be worked at a very considerable loss, but I am sure that public sentiment and the general social interest would never allow these services to be withdrawn, or even restricted. A public subsidy to the telegraph service may, however, be accepted without complaint, since it is the cheapest form of immediate long-distance communication and is available to all members of the public on equal terms. In this respect it differs essentially from the intercommunicating telephone, which is installed purely as a matter of personal advantage and therefore has no claim to a subsidy from non-subscribers. The combined telegraph and telephone switching (Telex) system, described by the author, is a pioneer venture which has attracted a great deal of attention both at home and abroad. So far it has no counterpart in any other country. A teleprinter switching service, with specially constructed exchanges, has recently been introduced in America, where thousands of private-wire renters who were already using teleprinters provided a ready-made clientele. In this country the whole service—subscribers and equipment—has had to be built up practically from nothing, and it is difficult to see how an effective start could have been made apart from the happy thought of using existing telephone exchanges for the purpose. This has meant making every telegraph signal consist of a short train of waves at a tonic frequency which will conform to the transmission conditions of a speech wave, and pass freely and naturally over loaded trunk circuits and across the filters and valves of telephone repeaters. No proposal has yet been put forward with the object of applying the switching principle to the public telegraph traffic between telegraph offices. Such a system would require a liberal provision of wires in order to avoid delay and waste of time. I think, however, that as the telephone trunk system develops, and as by-product circuits become available in increasing numbers, it may ere long be possible to operate a good deal of the main telegraph traffic of the country by means of through switching, and in this way to achieve considerable further economies in operation.

Mr. L. Simon: In 1928 I visited the United States at the head of the Commission of Inquiry to which the author refers. The Hardman–Lever Committee recommended that inquiries should be made abroad, but the idea of a commission of inquiry to the U.S.A. had actually been mooted before that Committee was set up. Nevertheless, it is always given the credit for the idea. I am not disappointed that the recommendations of the Commission have not been carried out precisely in the form in which they were made, because the members of the Commission deliberately attempted to outline a sort of ideal of what the telegraph service might be, and compromises were inevitable. The reorganization of the inland telegraph service in recent years is the most revolutionary change in the telegraph history of this country. It involves the disappearance of the Morse and Wheatstone systems, and an entirely new scheme of lay-out for large instrument rooms. Among the innovations are double tables, the liberal use of belt conveyors, the segregation of apparatus other than the actual instruments, the use of typewriters for taking down messages received by telephone, and the transference to the operating staff of the care and maintenance of instruments in the instrument rooms. The Commission appended to its recommendations a suggestion that the associations representing the staff, both operating and supervisory, should be called into consultation on these recommendations. This idea was adopted, and joint committees were set up with the associations concerned, whose co-operation has been very valuable. Since the present paper was prepared there has been under consideration a very large scheme for the introduction of voice-frequency telegraph working on all the main routes. Although we have not yet come to any decision, we are probably within sight of the time when this will

be the sole method of producing telegraph channels on the main routes. The recent improvements in the organization and methods of instrument rooms have led to a considerable saving of time, except in connection with delivery. A message may be sent from one end of the country to the other within 10 minutes of the time of handing it in, but it may take up to half an hour to deliver. These figures are disproportionate, and we hope to improve the ratio to some extent by the introduction of motor-cycles for delivery purposes. In addition, an ever-increasing proportion of telegrams will probably be delivered by telephone, or by teleprinter through the Telex system.

Mr. J. C. Besly: I am chiefly interested in the question of how far the factors which result in the suitability of teleprinters to internal circuits are applicable to overseas services. The satisfaction given by teleprinters is largely dependent upon the use of lines which cause little distortion of the signals, such as might be due to inherent line properties or interference. The teleprinter, owing to the fact that it makes use of the 5-unit code, is a dangerous instrument to use upon a circuit liable to much signal mutilation; there are 32 possible combinations in the 5-unit code, so that if a letter be mutilated, there are 25 chances in 31 that it will be turned into another letter. This feature makes the teleprinter unsuitable for use on most wireless services and long submarine-cable circuits when they carry a substantial proportion of code traffic. The liability of the teleprinter to error was brought to my notice in a case which occurred about a week ago. There was a long message of some 50 words, each word consisting of 10 code letters, and the whole message was absolutely intact and correct except for 5 consecutive letters, each of which was changed into another letter. The message was correctly recorded at the transmitting end, but at the receiving end there was no indication whatever that an error had been made. It was probably due to a temporary large speed-change.

Mr. H. Kingsbury: The telegraph service in Great Britain is a national necessity which has been awaiting reorganization for many years. In my opinion its importance does not need to be elaborated, and it will not in future need to be justified by an emergency such as failure of a main telephone cable, which, incidentally, will equally affect the telegraphs. The Leeds office I prefer to regard rather as one item in a comprehensive and well-conceived general advance than as an experiment. The use of a.c. motors for teleprinters seems to have been neglected. A self-contained machine, which would avoid the difficulty associated with batteries in a large office, might be designed if a compact d.c. generator with suitable characteristics could be devised; two such generators mounted on an a.c. teleprinter-motor shaft might supply line and local current, and the arrangement should be more efficient than the present combination of rectifier, d.c. motor, and batteries or oscillators. The author's statements on the disposition of racks (page 197) and on phonogram circuits (page 211) appear to exclude lay-outs occupying two or more floors; definite advantages may result from disposing a phonogram room immediately above or below the telegraph circuits. Combining the two functions as favoured by the author would improve the training scheme rather than the service. The circuit shown in Fig. 4 is described as unidirectional, although similar circuits have been duplexed in France. Fig. 28 would be a more accurate picture of the quality of maintenance if lost time could be expressed in terms of the circuit operating hours. Further information upon the practical efficiency of foot-operated time stamps would be valuable, and the relative gumming delay involved under the two conditions mentioned on page 209 appears to require elucidation.

Mr. J. S. Jones: A disadvantage of the process of mechanization which I have noticed in the Central Telegraph Office is that of increased noise in the instrument rooms. During the past few years, while mechanization has been going on, there has been a marked, though gradual, increase in the sick leave of the female staff. In the view of the medical officers this increase is probably due, in part at any rate, to the effect of noise on the nervous systems of the women. The telegraph service is becoming more and more an occupation for women rather than men. Five years ago, the ratio of men to women in the Inland Branch of the Central Telegraph Office was 2 : 1, but before very long the proportions will be reversed. The increase in the sick leave of the female staff is therefore very disturbing, and it is to be hoped that telegraph engineers will do all in their power to make the new machines as noiseless as possible. The reason for the apparently slow progress in the direction of mechanization is that, on account of the stoppage of recruitment during the past decade, the telegraph staff are no longer young. They have had to be gradually trained to operate the new machines, and it is a great credit to them to have achieved the efficiency in teleprinter working which is evident in any instrument room to-day. In the Central Telegraph Office at the present time over 70 per cent of the work is done by teleprinter. Unfortunately, the number of telegrams dealt with by the inland system has been declining for some years and is now almost at the same level as it was in 1886, the year after the introduction of the 6d. tariff.

Mr. L. S. Crutch: There can be no doubt that the new methods described with regard to the inland telegraph service will enable traffic to be handled more economically. It is stated in the paper that telegraphy is an ideal method of communicating simultaneously with a number of persons. Will this facility be extended to Telex subscribers? It would be a valuable feature for banks, police, and institutions, enabling them to give instructions to a number of branches simultaneously. I should like to know whether, to provide for the possibility of a breakdown rendering immediate communication impossible, a timed wire service such as that used by the Western Union Co. in America is to be introduced. This system makes it possible to transmit messages at the earliest possible moment without the sender of the message having to wait to perform the operation. Will public teleprinter booths, for use in conjunction with the Telex system, be installed at such places as the Stock Exchange and various racecourses? I should like to inquire the advantage of the double-phantom circuit over sub-audio telegraphy. The mention of the

vibrating relays used on the latter system leads me to ask whether these are entirely satisfactory.

Mr. C. J. Mercer: The problem of the telegraphs is that of putting the service on an economic footing. The "Post Office Commercial Accounts," a public document obtainable from the Stationery Office, shows that the annual deficit on the telegraph service is roughly £1 000 000, and that the engineering cost of maintaining the system, including salaries, wages, materials, and other incidental payments, is about £330 000 per annum, while the administrative and operating costs are £3 600 000 per annum. It will be seen, therefore, that the Post Office cannot hope to solve its telegraph problem by mere economy in engineering expenses. To improve the financial position it has to ensure that engineering expenditure designed to improve the service will also result in operating savings. Economies of this kind have been achieved by the improved methods described by the author, and these improvements have also increased the reliability and speed of the service. I do not think that the Post Office can be blamed for lack of courage in scrapping old methods or in adopting new ones. During the 10 or 12 years prior to the War, experiments were made with system after system of machine telegraphy—the Rowlands, the Buckingham, the Murray automatic, the Murray multiplex, and a number of others. None of these was abandoned until it was certain that it did not provide the type of service that was necessary. In recent years the Baudot system was developed and brought to a high state of perfection, but it was abandoned in favour of the teleprinter when it was clear that this instrument would give a higher operator output. The Telex system has created a great amount of interest in other administrations, so much so that in the near future we shall probably have to consider an international as well as an inland Telex service. Some differences of equipment will have to be overcome, but I do not think that these will present insuperable difficulties. By-product circuits are an exception to the rule that alternating current will be almost universal for telegraphs in the future. These circuits are worked by direct current, and I think that —in view of their make-up—they must continue to be so worked.

Mr. A. O. Gibbon: Reference is made on page 190 to the fact that there are 11 400 telegraph offices in Great Britain and Northern Ireland. It would be interesting to know the number of circuits included in this total which are equipped with teleprinter apparatus. On page 193, and in Fig. 28, it is stated that the average stoppage of teleprinter circuits during 1931 amounted to about 8 minutes per week. Is it possible to give a closer analysis of this lost time, showing how much is due to trouble with motors and how much to transmitting or receiving mechanism? The timing stamps mentioned on page 208 are expensive and represent an additional capital charge on an already heavily-burdened service. Is it contemplated that their use will be extended? I have been concerned during the past 6 years with technical examinations in the telegraph service of the British Post Office; my duties have included the selection of officers for the new testing and maintenance scheme, and the establishment of the special training school at headquarters. The arrangements for the technical education of the staff at this school are fully described in the paper. Although the training is mainly concerned with teleprinter apparatus, candidates are also trained in the testing of lines and the tracing of faults in other forms of telegraph apparatus. As there are approximately 650 separate parts in the mechanism of the teleprinter, careful attention to the maintenance of this machine is essential. It speaks well for the quality and adaptability of the personnel of the testing and maintenance staff that they have qualified for the duties, despite the fact that there has not been a great deal of technical literature available on the subject of the teleprinter. The testing and maintenance scheme provides for the employment of women, an innovation which has been fully justified by the results to date. The testing scheme was introduced into the Central Telegraph Office in April 1932, and is working satisfactorily. In that office, where 270 teleprinters are installed, the number of circuits reporting stoppages has been materially reduced since April last. The testing and maintenance scheme is now being introduced into the large provincial telegraph offices, where it is anticipated that similar satisfactory results will be obtained.

Dr. L. E. C. Hughes (*communicated*): The noise components emitted by teleprinters are: (1) Mechanical impacts, the noise caused by which is not reducible because of the fine manufacturing limits. (2) Bearing rumble due to motor unbalance, reduction of which demands dynamic-balancing and selection of high-grade ball-bearings. (3) Motor windage. (4) Commutator whine. Directly-radiated acoustic energy due to (1), (3), and (4), is markedly reduced by lining the cover with felt, but even then some of the energy escapes through the tape and ventilation holes. The felt has no effect upon (2) at 42 hertz, the major source of vibration. Although complaint was received of (4) at about 3 000 hertz, rather than of (1), measurement showed that the intensity of (1) greatly exceeded that of (4). When a number of machines, which cannot be governed together within a few cycles per sec., are placed near to one another, heterogeneous beats between the commutator whines probably become distressing. The problem of isolating (2) is solved by the use of slabs of cork or rubber, but unless the dimensions are calculated correctly such material is likely to increase the transmission of vibrational energy. Felt is useless for this purpose, because, apart from impossible dimensions, it "packs" and becomes non-resilient. Using a resilient species of cork, and adopting the principle that the vertical resonant frequency must be made low in comparison with the disturbing frequency (less than one-third, to be of practical advantage), the dimensions become 6 sq. in., 1 in. thick, for the No. 3A teleprinter, using a permissible static-loading. By experiment, the vibration communicated to the supporting table was found to be imperceptible to the touch when this cork was used. In use, the area of cork is divided to take the loading above the points of application, which must not exceed three in number, otherwise the loading cannot be determined and the design fails. Friction in the material reduces its value for vibration isolation. The fre-

quency is here too low for aural perception, but it may conceivably have a physiological effect via the feet or fingers.

Mr. E. H. Jolley (*communicated*): On page 207 the author enumerates four tests for checking the adjustment of a teleprinter, and on page 214 he states that "facilities for grading teleprinters" are an advantage of the new system. Do the four tests mentioned on page 207 constitute the "facilities," or are other means available for grading the teleprinters? I do not think that these tests alone provide a sufficiently sound basis for such grading. The receiving margin of a teleprinter is governed by several interdependent adjustments, including that of the electromagnet. To secure a margin of 35 per cent or more these adjustments have to be carried out with some delicacy, and the best results are secured when the adjustments are tested under actual running conditions. These adjustments must also be made so that the maximum margin is secured with the electromagnet neutral. In view of the importance of this question we have been carrying out experiments using a special teleprinter tester. A transmitter is used which is adapted so that distortion of known magnitude may be introduced into otherwise perfect signals. This enables the margin of a teleprinter to be measured. Tests of this kind probably give a clearer idea of the performance of a teleprinter than can be obtained by trials on artificial lines. I suggest that the use of this type of tester, to supplement the tests given by the author, would lead to an appreciable improvement in the working efficiency of teleprinter circuits.

[The author's reply to this discussion will be found on page 226.]

Mersey and North Wales (Liverpool) Centre, at Liverpool, 21st November, 1932.

Mr. H. H. Harrison: The most startling change mentioned in the paper is the adoption of teleprinter working to the almost entire exclusion of other systems. That this procedure is justified is shown by the remarkable man-hour figures given on page 194. The number of possible telegraph channels made available by the co-ordination of line plant, together with the greater efficiency of the single-channel printer, have led to the supersession of the Wheatstone and multiplex systems. In view of the fact that the national telegraph service is worked at a loss, vision and courage were required to institute changes involving heavy capital expenditure on new apparatus and the sacrificing of existing plant. Although the British telegraph system includes few circuits of a length approaching that of an international link, signal distortion will be unavoidable on some of them. Start-stop telegraphy must produce distortion owing to the fact that its mechanism rotates intermittently. If the time taken by the starting clutch is not constant, the received signals are subject to distortion, to which is added that produced by the fixed speed-difference between transmitter and receiver. Voice-frequency operation produces further distortion. I think that for long-distance teleprinter operation some form of regenerative repeater is required.

Mr. C. E. Reeve: Now that teleprinter working has been adopted almost any expert typist can become a telegraphist by taking a course of training in the methods used for handling telegrams. Temporary assistants taken on in Liverpool for the summer have turned out between 82 and 100 messages per hour, compared with the average of 36 for the Morse system. These figures suggest that the teleprinter system combines simplicity, ease of working, accuracy, and efficiency. The telegraphists on the permanent staff frequently attain figures of 100 to 120 messages per hour, and one has sent 128 messages in an hour, 71 being dealt with in the first 30 minutes. The teleprinter provides us with a means of transmission out of all proportion to the traffic available. With regard to international telegraphy, we work the Liverpool–Rotterdam service by teleprinter, and I think we have convinced the Dutch administration that this machine can do the work excellently. The Leeds lay-out is not quite as up-to-date as that at Liverpool, where the conveyors are worked on the low-level system. The table conveyors discharge on to a low-level band, and the outgoing and received traffic is carried by this band to the various points of the circulation table in approximately 25 seconds. Traffic to be forwarded is carried from the circulation table to the distribution points by similar bands in the same time. The period which elapses between the receiving of a message at one station and the forwarding from another is about 3·9 minutes: for specially urgent foreign messages this period is reduced to about 3·6 minutes. These figures show the superiority of the new lay-out to the Morse and Wheatstone systems. Although we still retain the Baudot system on some Continental circuits, we can now give an improved transit time from Liverpool to Hamburg of under 10 minutes.

Mr. J. Davey: The Liverpool–Rotterdam teleprinter system mentioned by Mr. Reeve is disappointing from one point of view, namely, that whereas a No. 3A teleprinter is in general use in the Liverpool instrument room, a No. 2A teleprinter is installed on the Rotterdam circuit. Perhaps the author could state why the Dutch authorities would not agree to the use of a No. 3A teleprinter, and whether there is any likelihood of teleprinter working to Continental cities other than Rotterdam.

[The author's reply to this discussion will be found on page 226.]

South Midland Centre, at Birmingham, 5th December, 1932.

Mr. T. Havekin: The successful provision for the concentration of circuits is a distinct advance in telegraph working. I notice that the amplification provided in the teleprinter circuit can be regulated; I should be interested to know who controls the amplification and how the need for adjustment is indicated. One is bound

to admire the enterprise which has resulted in the satisfactory operation of a double phantom circuit telegraph loop such as that illustrated in Fig. 4. The problems associated with the elimination of interference must have presented many difficulties, amongst which would be the accurate balancing of the lines. The cable manufacturers are entitled to no small tribute in this connection, for I suppose the specification with which they must comply is rather exacting. What are the limits of the frequency range employed in voice-frequency telegraphy?

Mr. W. P. Baines: I am especially interested in the subject matter of the paper because I was closely associated with the first teleprinter experiments in the London postal service—at Borough High-street Post Office. Faults, interruptions, and breakdowns were frequent in the course of the investigations, and these troubles continued for several months. It is unfortunate that the change-over to the teleprinter system has coincided with a marked and continued decline in telegraph traffic, probably in consequence of trade depression and the inevitable increase in the use of the telephone. The decision at such a time to re-equip the telegraph service, to improve it in every possible way so as to enable it to perform its function with the utmost efficiency, is a spirited one, but it has a rather sad side. Mechanization must lead to staff redundancy, which, added to the redundancy already produced by the decline in traffic, makes the position of the staff a serious one.

[The author's reply to this discussion will be found on page 226.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 13TH DECEMBER, 1932.

Mr. T. E. Herbert: The telegraphs were developed as a public service rather than as a profit-making industry, and we must therefore not regard the loss on telegraphs as something which should not occur. As the author points out, the telegraph is the only correct method of simultaneous communication of information to a large number of places. Scotland Yard has developed the teleprinter to meet its needs, and the Lancashire police have followed suit. In the course of a short time I think we shall find that throughout the country the police will be employing a telegraph system of the teleprinter type. I think, too, that the teleprinter will have a very definite sphere of utility in business. As the author remarks, the telephone and the telegraph should supplement each other. A telephone should be used for discussion only. If the message consists of an inquiry it should be sent in the form of a telegram. I look forward to the day when every business of appreciable size will have to use the Telex service. Turning to the subject of the co-ordination of line plant, there are several ways of using telephone physical circuits for the dual purpose of telephony and telegraphy. First, a sub-audio frequency may be used for the telegraphs; secondly, there is the double-phantom system, which will have only a limited application because of the number of circuits involved for each particular channel; and thirdly, there is the voice-frequency system, which gives 18 channels on a single pair of wires. It does not disturb the telephone circuits in the same cable, and it involves no special precautions at the telephone repeater-stations. I am disposed to think that this is the system which will ultimately survive. There is a vital need for a satisfactory small a.c. motor for use in connection with the teleprinter. I notice that the author devotes little attention to telegraph repeaters, presumably because they may be regarded as dead.

Mr. W. S. Hartley: I should like to refer particularly to the statement, which appears on page 197, in regard to the principles of segregation and rack mounting. About 2 years ago six of our London–Manchester telegraph channels were worked experimentally on the voice-frequency principle, and whenever a fault occurred we had to ring up the telephone-repeater room, perhaps merely in order to obtain a slight relay adjustment. A similar difficulty was met with at the London end, where the Central Telegraph Office had to ring up the Telephone Exchange at Carter Lane in order to obtain any necessary adjustments. Sometimes it was difficult to convey over the telephone exactly what was required, and personal visits had therefore to be made to the repeater room. We obtained a line efficiency of 90 per cent over the voice-frequency channels, the remaining 10 per cent being lost in communicating with the repeater room. We on the traffic side therefore claim that the ideal position of the apparatus racks and voice-frequency panels is as near as possible to the working positions in the instrument room. They should be under the full control of the testing and maintenance staff.

Mr. H. M. Turner: The phonogram equipment described by the author has already been modified, the associated amplifiers having been superseded in more recent designs. The sweeping changes which are now being introduced are likely to create the impression that the telegraph service has hitherto been dormant. In actual fact, however, the new apparatus has only been made possible by recent developments in the design of telephone equipment, from which the ideas embodied in the new telegraph racks have been borrowed extensively. The Telex service, for instance, depends upon the high efficiency of the thermionic valves which are now available. The author rightly omits to mention the provision of additional telegraph channels by voice-frequency methods. This feature, together with the developments described in the paper, will be responsible for revitalizing the telegraph service. The universal introduction of the teleprinter is bringing to notice the problem of distortion, a feature which will require very considerable attention if successful working is to be obtained. In the teleprinter, distortion takes new forms not previously met with in telegraph practice.

Mr. H. J. Moores: An additional reason for segregating all apparatus other than teleprinters is that this method enables a few men to control the circuits, and when they become familiar with the apparatus it will be a matter of moments only to discover the cause of most of the difficulties which arise. I do not think

Mr. Hartley's reference to the first voice-frequency system used in Manchester is quite fair. The old system differed from the modern rack-mounted apparatus in that neither Morse key nor teleprinter was available for localizing purposes, but on the whole the system worked well in spite of this. The fact that there are now few stoppages of circuits due to teleprinter working is perhaps due to the ample provision of spare instruments. The No. 7A teleprinters for subscribers are open to mechanical improvement. Although these instruments are expensive, it might be wise to spend a little more on their manufacture. With regard to the question of repeaters, will not these still have their value for made-up circuits and for special events? Could not telephone-type slow-acting relays be used on repeaters? Why has 300 cycles per sec. been selected for the Telex service? This frequency is on the lower edge of the normal speech band for which our main lines are designed, and it is a value at which a steep rise in the transmission curve can be expected. It therefore does not follow that a satisfactory speech line would prove to be a good Telex line. Measurements on a main line gave the following values: 800 cycles per sec., 8 decibels; 500 and 400 cycles per sec., 6·9 decibles; and 300 cycles per sec., 10·6 decibels. I am inclined to think that the terminal-switching losses will be comparatively high when measured at 300 cycles per sec., and if this is so it would seem that there is a case for adopting a higher frequency. Can the author give any information as to the transmission equivalent at 300 cycles per sec. of typical terminal switchings, i.e. cord circuits, junctions, subscribers' lines, and extensions? I think we should have a Telex system capable of being superimposed on any telephone connection that can be set up, without the necessity for calling in special staff.

Mr. B. J. Bitton: The panels associated with the voice-frequency system tried at Manchester were situated on another floor, which meant that when a slight adjustment was necessary one had to go to the telephone, ring up the operator, have the adjustment made, and then return to see if the fault had disappeared. Traffic officials are unanimous in asking that panels should not be segregated from the instruments to be worked, but should be placed as near as possible to them, so as to allow of small adjustments being made by the man on the spot. Harmonics gave trouble on the original Manchester system. In this connection, I believe that the difficulty of constructing a filter with a very sharp cut-off will be overcome. With regard to teleprinters, one or two alterations which would not be difficult of accomplishment seem to be desirable. One is concerned with duplication for Press copies. As Manchester has seven or eight daily newspapers we frequently have to make as many as eight copies. The teleprinter only makes one, and we cannot often, as at Leeds, couple teleprinters together, because we have not a sufficient number. With regard to the protection of contact points, on teleprinter No. 3A the contact points, being exposed to oil from the rapidly-moving parts, become so sooted and oiled up as to be ineffective. Perhaps something can be done to avoid this. I observe that in previous telegraph installations all the cables running to the instruments have been placed under the floor. Except from the æsthetic point of view, this seems to be a wasteful method. Apart from an objection on the score of appearance, there would be no disadvantage in running them at waist-level along the main corridor.

Mr. F. Akister: On page 197 it is pointed out that the ideal method of housing the racks would be to install them in a position remote from the instrument room. The phonogram apparatus, which is ideally suitable for an isolated position, is fitted immediately above the feet of the operator. I think that in this case it would be worth while to consider transferring the apparatus to an isolated position. It would be better from the maintenance point of view, and it would not necessitate taking the operator from the position in order to make adjustments. At Manchester high-efficiency headphones are being provided instead of amplifiers. This, apparently, is an improvement, and must be very much cheaper. I should like to know whether the author has had experience in the use of high-efficiency receivers instead of amplifiers. On page 194 reference is made to the weight of the teleprinter machines, and apparently difficulty is experienced in moving the teleprinter instrument from one position to another. It is suggested that it might be possible to provide for multiple beds; i.e. to arrange the tables in multiples of six, using a casting of some kind, in which the apparatus could be jacked or withdrawn as a unit, and so leave the bulk of the weight behind. In addition, it might be possible, by using this multiple-bed system, to drive the teleprinters by means of a shaft, and to synchronize the motors at the end of the shaft. Duplicate motors would be necessary for repairs, and in case of breakdown.

The Author's Reply to the Discussions at London, Liverpool, Birmingham, and Manchester.

Mr. R. P. Smith (*in reply*): The contributions to the discussion by the Engineer-in-Chief of the Post Office (Col. Sir Thomas F. Purves), the Director of Telegraphs (Mr. L. Simon), the Controller of the Central Telegraph Office (Mr. J. Stuart Jones), and the Staff Engineer of the Telegraph Section, Engineer-in-Chief's Office (Mr. C. J. Mercer), add valuable information which serves to reveal the altered conditions under which a comprehensive re-organization of the telegraph service was justified; they supply a reasoned and authoritative statement of the need for changes, the technical aspect of which is, more particularly, the subject of the paper.

In reply to Mr. Harrison, the preference of the Post Office for accumulators as a source of supply for telegraph circuits arises from their stability and suitability for use with the universal battery system. Failures of power are practically unknown so far as this supply is concerned, and the voltage remains constant under all conditions of load. Fig. 6 shows the overall figures used as a basis for the provision of staff. They comprise all types of traffic and make allowance for losses of various kinds; for example, those due to traffic fluctuations and line interruptions. The flow of traffic to be anticipated each hour is obtained from tablet returns taken at stated

intervals. In certain circumstances the actual, average, overall output per operator per hour may be less than the figures shown, but the potential output in individual cases when sufficient traffic is available is very much higher. (The figures quoted by Mr. Reeve are interesting in this connection.) In the normal case a duplex channel is staffed by two telegraphists at each end of the circuit; a system of duplex-simplex working has been introduced recently and gives excellent results. In this case there is one telegraphist at each office. The circuit is balanced for duplex working, but each telegraphist occupies the sending and receiving positions in turn, sending five messages or less as available, and then dealing with the batch received meantime. Totals of 80 to 90 messages per hour per operator are frequently made.

Mr. Besly raises the question of the suitability of the teleprinter for working on long cables or on long submarine circuits. The experience of the Post Office in this direction is limited to a few circuits, and to tests carried out between London and the Continent. The London–Dublin and London–Jersey teleprinter circuits are routed partly in underground and partly in submarine cables. The latter circuit has a telegraph repeater inserted at Exeter and the transmission is automatic. The quality of the service given is quite satisfactory. It is the practice of the Post Office to repeat at the end of each transmission any figures or code words contained in a message; an error such as that quoted would thus be detected, but of course additional transmission time is occupied by repetition, a matter of some importance on cable circuits.

With regard to the criticisms of Mr. Kingsbury, the difference between the carrying capacity of a 2-wire circuit as between telegraph and telephone users must not be overlooked. In the case of a breakdown limiting the number of telephone circuits available, these can serve but a small number of would-be users, compared with the large number whose communications may be dealt with telegraphically, on one circuit; a duplex channel in an emergency will deal with 200 messages per hour. The Leeds installation was an experiment in the fullest sense of the word. It is impossible to embark upon wholesale changes affecting the conditions of service and prospects of a large body of workers without prior consultation with representatives of the staff associations concerned. (Mr. Simon deals with this aspect of the matter in his remarks.) It has been found possible to accommodate the phonogram room in close proximity to the telegraph instrument room, on the same floor, at all re-organized offices with the exception of London. The conveyors to and from circulation points form part of the general telegraph installation, and a minimum amount of time is lost in making any necessary staff-changes. So far as Post Office practice is concerned, it is difficult to see what "definite advantages" could result from having the rooms on separate floors. It may be stated that the fusion of telegraph and phonogram staffs which I anticipated has now been accomplished. The type of circuit illustrated in Fig. 4 has not been used as a duplex channel in this country, although experimental trials have proved the practicability of duplex working should the need arise. It is regretted that information necessary to amplify Fig. 28 as desired is not available. It may be remarked, however, that the number of circuits has been rapidly increasing, whilst the average traffic time lost has fallen steadily. The number of circuits covered by the chart is as follows: December 1929, 120 circuits; December 1930, 344 circuits; and December 1931, 614 circuits. The majority of these circuits are working from 8 a.m. to 7 p.m. The efficiency of timing-stamps operated by mechanical means proved inferior to that of machines of the electrical type during the exhaustive trials referred to on page 208. The wear of shoe leather and the liability of the tubing for the valve to become entangled between the instrument table and the floor were objections to the pedal-operated type. The advantage of the gumming equipment when used on lightly loaded circuits arises from the avoidance of delay to messages. The length of slip between the nozzle of the bottle moistener and the teleprinter platen must be drawn out for each message. This length of slip is wet and messy to dispose of; it also represents waste. In addition, the small portion necessarily drawn over the wheel dries rapidly and must also be discarded.

In answer to Mr. Crutch, simultaneous transmission over the Telex system is not provided for. The Post Office will undertake, however, to install and maintain on rental terms a private-exchange network, allowing messages to be broadcast by teleprinter to as many as 30 points, or less, as required. Communication in both directions is arranged for. The demand for such installations is increasing rapidly. The other services suggested are possible developments of Telex working when the system has secured a sufficiently large clientele. The use of existing by-product channels to form double-phantom circuits is economical, since they cannot be used for telephone circuits. Unidirectional working is the rule, and this avoids any loss of traffic time due to balance adjustments. Relays of the vibrating type are in general use for circuits having a considerable portion of underground cable in their make-up. Their behaviour is quite satisfactory, the working margin of the circuit being improved up to 50 per cent.

With regard to the points raised by Mr. Gibbon, there are 336 telegraph offices supplied with teleprinters, and, in addition, 7 railway stations where public traffic is received for transmission. The number of teleprinter circuits is approximately 650. Fig. 28 refers purely to traffic time lost; it conveys no information as regards stoppages due to line or power failure or as regards the nature of instrument trouble. Spare teleprinters are always available in the instrument room, and if a stoppage exceeds a few minutes the machine is changed. The desired analysis is available from other records. During September, 1932, the faults dealt with by the engineering department were scheduled as follows:—

	Per cent
Faults in motor	24·4
,, ,, governor	11·1
,, ,, transmitting parts ..	17·3
,, ,, receiving parts	23·1
,, ,, printing parts	13·9
,, ,, carriage operating parts	5·0
,, ,, wiring	5·2

The use of timing-stamps and numbering-machines will be limited to important circuits where sufficient traffic

exists to maintain a constant flow. On such circuits the increased output justifies the provision of stamps.

Dr. Hughes's analysis of the noise arising from a working teleprinter is very interesting, and will materially assist the sustained efforts that are being made to reduce noise to a minimum. It would, I believe, be generally conceded by telegraph officials that instrument rooms are very much quieter under the new conditions than at any period during the predominance of Wheatstone and multiplex working. The noise arising from perforating, stick or pneumatic, Creed re-perforators and printers, with other apparatus used for Wheatstone working, was deafening in any large instrument room. The volume of noise to-day is more comparable with any clerical establishment where typewriters and similar machines are largely employed.

I entirely agree with Mr. Jolley that a tester designed to measure the permissible margin of signal distortion is an excellent method of grading teleprinters. When the panel-mounted equipment was introduced at Leeds, it was discovered that after a circuit had been proved good as between the test-bay operator and the distant office, difficulty in reception sometimes occurred when the circuit was put through to the operating position. In most cases this was attributable to variations in the adjustment of teleprinter electromagnets. The teleprinter test-table described provides facilities for standardizing with a minimum current the electromagnets at a common operating level; neutrality is determined by electrical means, instead of by mechanical means as formerly. The trouble was largely removed by these test facilities. The tester designed by Mr. Jolley is expected to be available in the near future.

In the Liverpool discussion Mr. Davey calls attention to the disadvantage of having teleprinters of different types in the instrument room. This difficulty does not arise in the inland service, and in the particular case cited the wishes of the foreign administration were met.

In the Birmingham discussion Mr. Havekin has perhaps misunderstood a reference to amplifiers. Telephone-telegram-typewriter and phonogram panels have amplifiers associated with the key-shelf equipment, enabling operators to introduce and regulate amplification of speech; but typewriters, not teleprinters, are used at these positions. The frequencies for multi-channel voice-frequency telegraph circuits have been fixed by the Comité Consultatif International as follows: The first channel is worked with a frequency of 420 cycles per sec., and subsequent channels are spaced 120 cycles per sec. apart, up to the normal maximum frequency of 2 460 cycles per sec. for such systems.

In the Manchester discussion Mr. Herbert anticipates the predominance of 18-channel voice-frequency circuits in telegraphy of the future. A considerable advance in this direction is likely to be made this year. Telegraph repeaters for inland circuits will then disappear almost entirely, as voice-frequency circuits are accommodated by the normal repeater equipment at telephone repeater stations.

Mr. Hartley and Mr. Bitton refer to maintenance difficulties on a voice-frequency system working between London and Manchester during the period 1926–1932. The points raised are of an administrative character, with which I am not competent to deal. In reply to Mr. Bitton, it may be stated that teleprinters of the latest type (No. 7A) are arranged to provide for multiple copies; protection is also afforded to the transmitting contacts.

Mr. Moores quotes measurements taken to compare the transmission efficiency of lines at various frequencies. The values quoted are recognized, but the frequency of 300 cycles per sec. has certain very definite advantages for use on lines used jointly for telephone and telegraph purposes, and these advantages were considered to outweigh the objection referred to. Generally, the attenuation of unloaded cable pairs used on subscribers' lines is less at 300 cycles per sec. than at 800 cycles per sec. Measurements were taken on many types of terminal apparatus, cord circuits, etc.; the results did not, however, show any reason to affect the general adoption of a frequency of 300 cycles per sec. for Telex working. Slow-release relays of the telephone type were tried experimentally on a number of telegraph repeaters, with a view to replacing the automatic switch. After prolonged trial, certain disadvantages became apparent and their use was not extended.

The phonogram apparatus in the position referred to by Mr. Akister is proper to the cord circuit, and could not conveniently be removed with other apparatus to a remote point, on account of the very considerable amount of cabling that would be involved. It is hoped that the high-efficiency headphones referred to will make it unnecessary to install amplifiers for new work, but the result of experimental trials now in progress has not yet reached the stage where a final comparison of the two methods can be made. Even with the type of receiver referred to, a volume control is required, and is furnished by means of a resistance unit on the key-shelf. The suggested method of dealing with teleprinters at the instrument table could not be adopted with the new system of double tables and continuous V-belt conveyors. The teleprinter must necessarily be removed as a whole; it is not possible to reduce materially the weight of 80 lb.

SOME CHARACTERISTICS OF SHORT-WAVE PROPAGATION.

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SUMMARY.

In Part 1 of the paper is given a description of the phenomena observed when using a cathode-ray direction-finder on closed coils for examining received signals on frequencies of the order of 10 000 kilocycles per sec. The two outstanding features are the systematic appearance of certain cyclic forms, and the large values obtained for the horizontally polarized electric components.

The former are then examined in the light of the magneto-ionic theory, and it is shown that the majority of them admit of simple explanation on this basis. The latter are chiefly of interest in raising the question of angle of incidence, which appears to be much less than is generally supposed; and Part 2 is devoted to a more detailed examination of the question.

GENERAL CONSIDERATIONS.

In view of the increasing use of short waves for radio communication, considerable interest attaches to a study of the polarization of the received wave. This can be viewed in two lights—an inquiry into the actual polarization of the wave received from a distant transmitting station, and also the more theoretical one of the causes producing it and their correlation with atmospheric phenomena.

The first of these is, within limits, definitely soluble in that it is possible to specify most, if not all, of the components of the arriving wave; but the second does not admit of formal complete solution by purely deductive analysis; and as a certain amount of inductive reasoning is necessary the results must be more of the nature of reasonable explanations than direct proofs.

The particular effect that causes these limitations occurs equally in long waves, though owing to the simpler form of long-wave propagation it is not quite so serious. It may be stated as follows. The arriving wave consists of one or more waves refracted from the upper layer (assuming transmission from such a distance that the ground wave is negligible). Each of these waves may be broken up into two components, with their e.m.f.'s in the vertical plane and the horizontal plane respectively. Now with any kind of coil receiving set the only three quantities which it is possible to measure are the resultant electric force in the plane of propagation, the resultant perpendicular to that plane, and the phase difference between them, or some combination of these. Physically, of course, each of these components is itself a resultant of all the corresponding components of the various downcoming waves, and it is this second separation which is instrumentally impossible. The only method of attack, other than a pulse method, is to study the behaviour, both relative and absolute, of these components, and from their variations to reason back to their probable causes. In addition to this it is possible to measure with a coil and a vertical aerial the actual angle of incidence (provided this is not very large), and such results are given in Part 2.

Owing to the rapidity with which the changes take place, the only possible methods of measurement are visual or photographic. The former have been used considerably, though they suffer from the defect that the results cannot be stated in tabular form, but must be descriptive, and adequate descriptions are difficult to convey to anyone who has not actually seen the effects. Photographic records are also used to a certain extent, but their employment is often limited by instrumental complications.

Part 1.

Instrumental Details.

There is no doubt that the chief factor that has hindered the development of work of this nature has been the instrumental one. The instrumental demands are peculiarly exacting, and the difficulties of eliminating small errors at high frequencies very great. The deceptive simplicity of the apparatus required merely to receive short-wave signals is liable to mask the problems which arise when a form of reception is required conforming to a given specification within a small percentage limit. At the same time it is useless to employ apparatus unless its limit of accuracy is known sufficiently well to enable discrimination to be made between actual results and those due to instrumental shortcomings.

With regard to the apparatus itself, apart from the internal difficulties which arise from the pronounced effect due to small stray couplings at high frequencies, the nature of the received signals imposes two very important limitations. The first of these is that, due to the rapid fading which occurs, all readings must be strictly simultaneous if they are to be mutually comparable. On the longer waves it is possible to work by successive observations, provided the interval is not too long; but in this case, where a complete fade may only occupy one or two seconds, absolute simultaneity is essential. Again, the various pieces of apparatus required must be not more than a fraction of a wavelength apart (see Naismith*).

While a fraction of a wavelength of several kilometres is ample to secure freedom from mutual interference, the same fraction of a wavelength of 30 m may be only a few feet. The problem therefore is to produce instruments which will work in close proximity to one another on the same station at the same time without mutual

* See Reference (1).

interference, and these essential requirements have led to the production of apparatus which, viewed from ordinary standpoints, is definitely abnormal.

The apparatus used for the investigation consists of a cathode-ray direction-finder working on closed coils. A schematic diagram is given in Fig. 1. The set is worked on closed coils in order to include the horizontally polarized component which is essential from the theoretical standpoint. Theoretically their orientation is unimportant, but there are practical advantages in the definite N-S and E-W positions.

In actual working, with the exception of the special high-frequency unit, the cathode-ray apparatus is that developed at the Radio Research Station for longer-wave working, but on the present set only a single frequency change is used, i.e. the change is straight to 2·5 kilocycles per sec., the normal working frequency of the tube outfit. This was done for instrumental simplification, but it limits the available amplification to that in which the general valve and amplifier noises are the limiting factor.

As regards sensitivity, a gradient of about $10\mu V/m$ at a wavelength of 30 m gives a diagram about 2 cm long on the tube. While this is not the smallest that can be seen, it represents about the limit at which useful observation is possible, though in the latest design this sensitivity has been increased without serious instrumental complication.

The cathode-ray outfit gives at any instant an ellipse, and by noting the major and minor axes of this and their direction it is possible to calculate by ordinary geometry the resultant e.m.f.'s which would be induced in two vertical coils in the plane of propagation and at right angles to it, and the phase angle between them. The relation between the latter of these two e.m.f.'s and the corresponding space e.m.f. depends, of course, on the angle of incidence. A somewhat similar method was used by Friis,* except that in his case the receivers were definitely spaced apart and not on a common axis. (For fuller instrumental details, see the Annual Report for 1931 of the Radio Research Board.)

Method of Observation.

As a preliminary study, observation was kept to determine characteristic behaviour. At first sight the ellipse on the tube generally appears to be in a state of violent irregular oscillation, but on closer study it is often possible to pick out visually certain definite characteristics. On particularly favourable occasions one particular form may appear either alone or in great preponderance, and such occasions are specially useful.

The presence of an ellipse shows that in general there is an abnormally polarized wave present. While this ellipse may partly be caused by imperfect reflection from the ground, the speed and amplitude of its variation suggest at once that this is not a controlling factor. The actual size of the ellipse at any instant may be affected by this, but it is difficult to believe that it can vary sufficiently in magnitude and time to be a preponderating factor. This is discussed in greater detail later.

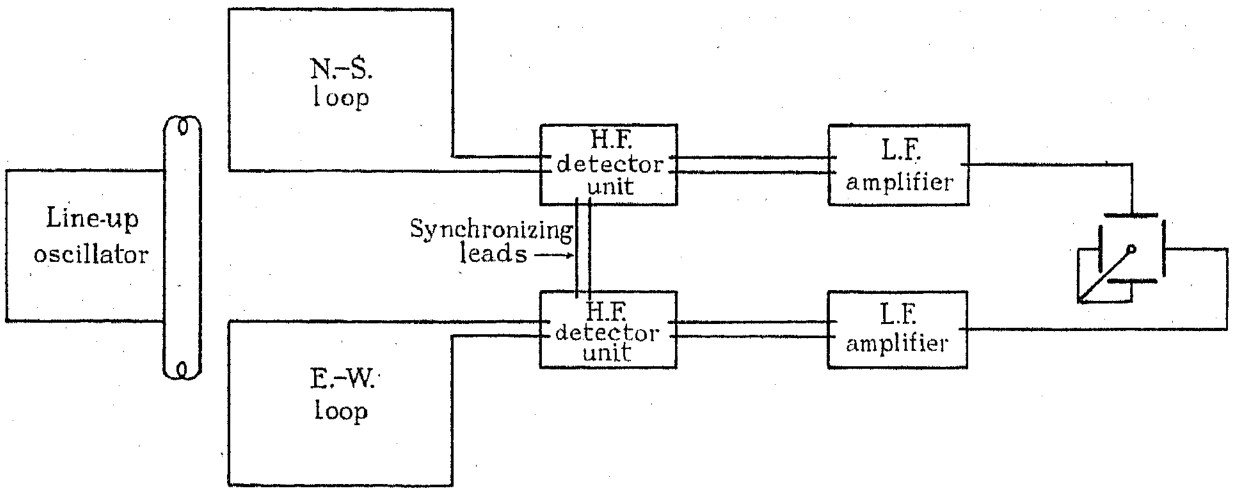


FIG. 1.

* See Reference (2).

Fading.

This may be either intensity or phase fading, and may be selective or not. In general, phase fading will be expected to show some periodic deformation of the ellipse. As a general characteristic, periodic variations of any nature suggest that their primary cause is phase variation, and since the change in path-difference due to the existence of two separate ray paths for a complete phase-fade cycle is only 1 wavelength, very slight differences in path are sufficient to cause it. Phase-fades should therefore be comparatively rapid, and several complete cycles are likely to occur. This is borne out by the observations where the periodic changes usually have only a period of a few seconds. The longest recognizable one observed so far had a period of 38 sec., repeated several times. On the other hand there has so far been no sign of any very rapid variations, i.e. with periods of a fraction of a second.

General intensity fading gives a change in the size of the ellipse without change of shape. It is usually quite slow and irregular. On steady occasions during summer day-time it may take several minutes to pass from a maximum to a minimum. On very disturbed occasions it will occur in addition to phase fading and is then more difficult to detect. Readings have, however, been obtained during which only one kind of fading was present; in the case of phase fading this is shown by the constancy of the intensity during a phase cycle.

Classification of the Ellipse Variations.

(1) *Straight Line.*

Although the ellipse is the most general form, the occurrence and persistence of a straight line is one of the first facts to strike an observer. Even on very disturbed days the ellipse is continually passing through the straight-line form, and on steady days it may persist for long periods. Straight-line form is not associated with any particular direction. The line may oscillate about a mean position or steadily rotate, both effects being very frequent. It cannot therefore be explained by the existence of a single normally-polarized wave, since this would demand lateral deviations up to 360°, but must be due to some frequently repeated, and therefore probably simple, relation between the components. Its occurrence is too frequent to be explained on a basis of probability by the chance relations between the many independent variables involved.

(2) *Rotating Ellipse.*

In this form the signal gives an ellipse, the major axis of which makes one or more complete rotations in either direction. The eccentricity of the ellipse is not constant throughout the revolution but often repeats at certain points.

(3) *Oscillating Ellipse.*

Here the ellipse does not rotate, but rocks backwards and forwards about a mean position. In this case the axis often has a corresponding cycle of magnitude; in fact the whole ellipse looks as though the ends of the major axis were describing two circles whose centres lie on its mean position.*

(4) *Circle.*

The signal will occasionally form an almost perfect circle which persists for some seconds (up to about 30).

(5) *Pulsating Ellipse.*

The ellipse keeps fairly steady with its major axis in a direction approaching the geographic bearing. The major axis has rapid periodic pulses of at least double its normal intensity, but without appreciable change either in direction or in size of minor axis. This effect is most pronounced on distant stations.

(6) *Inverting Ellipse.*

A normal ellipse forms and then suddenly the major axis shrinks and the minor increases so that an ellipse at right angles to the previous one forms without rotation. This only occurs on disturbed days and happens so rapidly that it is sometimes difficult to observe. It does not appear to be associated with any particular direction of the axes.

(7) *General Fading.*

This alters the size of the ellipse without affecting its shape or direction. It is generally slow and irregular. When absent, as often occurs, the cyclic phenomena (1) to (5) repeat with constant amplitude, otherwise the cycles are still present but with steadily varying amplitudes.

The following are the stations whose signals have provided the data for the above analysis:—

	Wavelength	Distance
Zeesen	31·38 m	920 km
Bandoeng	31·86 m	11 880 km
Saigon	31·6 m	10 210 km
Oslo	30·06	1 080 km
Nauen*		920 km
Aranjuez† ..		1 280 km

Theoretical Analysis of the Ellipse Forms.

The following analysis of these forms is based on what is now known as the magneto-ionic theory. This was first suggested by Prof. E. V. Appleton‡ in the discussion at the meeting of the Physical Society of London on the 28th November, 1924, when he pointed out that if the electric charges in the upper atmosphere were carried on electrons the theories of Eccles§ and Larmor|| would require revision. Such revision, together with further developments, has since been carried out by him and also by Hartree¶ and Goldstein**; and the work in this paper is based on their calculations.

From this theory it is predicted that in general each upgoing ray will be split into two elliptically polarized components with opposite directions of rotation which recombine on emergence from the layer where they have suffered differential phase-change and absorption. At these wavelengths, from the calculations given by Goldstein it appears that the polarization is almost perfectly circular except for the case (which actually does not arise) of propagation with a direction transverse to the earth's magnetic field, and for frequencies less than about 100 kilocycles per sec.

As a primary effort, therefore, an attempt will be made to fit in the observed ellipse characteristics with this theory. Theoretically, of course, this is always possible, since the ellipse yields three variable parameters to correspond to those of the theory, namely, the intensities and phase relation of the two components. This is, however, modified by the following important reservation. If a distinctive effect of simple nature is of frequent occurrence, its cause is to be looked for in some simple variation of propagation conditions and not in the chance occurrence of some elaborate relation between the three primary components.

Returning to characteristic (1) on this page, it is shown in Appendix I that the steady rotation of the straight line is yielded by the existence of two equal circularly polarized components whose relative phase changes but not their intensities, the direction of rotation depending on whether the path difference is increasing or decreasing.

Characteristics (2) and (3) are similarly shown to be due to the same cause when the original intensities are not equal, there being a definite limiting relation between these intensities at which rotation changes into oscillation.

* (2) and (3) may occur simultaneously. In one observed case the ellipse as a whole rotated twice at the rate of 38 sec. per revolution, during which 25 small pulses of type (3) occurred with perfect regularity.

* Including DUA (27·47 m), and DGU (31·09 m).
† Including EAQ (30·42 m), and EAJ (25·1 m).
‡ See Reference (3). § *Ibid.*, (4). || *Ibid.*, (5).
¶ *Ibid.*, (6). ** *Ibid.*, (7).

Characteristic (4) is evidently due to the total disappearance of one component.

Characteristic (5) is rather more complex.

So far only one returning refracted signal has been considered, composed of two components recombined on emergence from the ionized region. The note to (3) on page 231, however, suggests that more than one complete ray is occasionally present, since it would be difficult to obtain the doubly cyclic variation by any other means. If the downcoming angles of these are very different it would be possible for variation of the one at higher angle of incidence to give a result like (4). For a detailed discussion of this, see Appendix 2.

Characteristic (6) is discussed and explained mathematically in Appendix 1 as due to a certain numerical relation being approximately but not exactly satisfied.

Sequential Effects.

Up to this point we have described, as a preliminary attempt at systematization, various ideal signal forms extracted from actual observations by a form of analysis. The next stage is to consider the relations between these forms in time, i.e. to study actual signals and see how the change from one form to another occurs. For this purpose again a certain selection is necessary, since all signals are not equally suitable for the purpose. For instance, they may be unusually weak, or steady for long periods in one standard form, or, as sometimes occurs, varying so rapidly that eye and mind cannot fully appreciate and analyse their behaviour. On favourable occasions, however, the effects occur in a marked form at reasonable speed, and it is from such a selection that the following results are mostly deduced.

The first one was experienced in almost perfect form on the 15th October, 1931, and is typical of a sequence which is of frequent occurrence though not always in such perfection.

The following is a copy of the actual entry in the log.

"*DGU. October* 15*th*, 1931.

At 1425 G.C.T.; made several revolutions in the left-hand direction as a straight line of uniform length. Also gave almost perfect circles for several seconds. Changes of intensity small.

At 1435 gave a large circle, then faded out for some time.

At 1443 returned as a large ellipse with major axis in the geographical direction, some general fading.

At 1446. Rotating ellipse.

At 1447. Rotating straight line, period 28 secs."

Now on the basis of the theory already given these results may be at once analysed as follows:—

1425. Both components present of equal intensity but varying phase.

1435. One component vanished, leaving the other intact for some minutes; the second component then vanished too.

1443. Second component returned.

1446. First component also returned but at less intensity than the first.

1447. The two components again became equal.

In view of the importance of these results it is interesting and instructive to carry the analysis further, but in doing so it must be noted that we at once pass to the realm of hypothesis and suggestion, and consequently the ideas obtained must not be looked on as rigid facts of the observational type, but rather as ideas for which justification is to be found in their power of suggesting explanations to be confirmed or disproved later by further experiment.

Now one of the most interesting facts in this observation is the slow period of revolution of the diagram (28 sec.). This rotation has been explained as a phase interference on theoretical grounds, but it has been confirmed by the two following observations.

(1) On one occasion a station (unknown) was found using marking and spacing waves differing by a few hundred cycles. On tuning this in, it was found that the two waves gave different ellipses on the tube, their axes being inclined at about 60°. It was evident, therefore, that a change of frequency of a few hundred cycles in about 10 000 kilocycles was sufficient to produce a definite change of interference phase.

(2) On another occasion a station was heard whose note tended to fall towards the end of each dash, apparently due to load on the transmitter. Exactly corresponding to this drop the ellipse on the tube turned through about 10°. It seems, therefore, that there is abundant evidence that these rotations are caused by phase interference.

Now, as has been mentioned above, the change in path length required to produce one complete interference cycle is only 1 wavelength [in the case of DGU (31·09 m)]. That is to say, in the above observation in a total transmission distance of nearly 1 000 *kilometres* the reduced paths of the two components had only a relative rate of change of about 1 *metre* per sec. Further, even on more disturbed days this rate of change remains of the same order, though it may be increased 20 or 30 times, and it is difficult to avoid the following conclusions:—

(*a*) That (except possibly at special times such as sunrise and sunset) the layer is reasonably uniform and steady and does not present abrupt variations and discontinuities.

(*b*) That the separation between the two paths is small.

To discuss the second point further needs another excursion into theory.

According to the full mathematical development of the theory the upgoing ray on striking the ionized region is split by double refraction into two components. The paths of these components are determined by the relation between the density N and the refractive index μ, this relation being given by a complex vector equation which allows for the effect of the earth's magnetic field. Now one particular advantage of the transmissions from Nauen and Zeesen is that throughout their path the direction of transmission is almost exactly at right angles to the earth's magnetic field. The same is true for the latter part of the path from Bandoeng (Java), though there is some departure from it (about 30°) in the early stages. Under these conditions the μ^2, N equation is considerably simplified and admits of fairly easy arith-

metical solution. This has been worked out by Dr. Mary Taylor, and Fig. 2 shows the result for Zeesen and Rome. It will at once be noticed that for all reasonable values of N the two values of μ lie very close together, their separation not exceeding about 7 per cent. This is a further confirmation of the experimental conclusion that the separation between the paths is small.

Again, from the relation that the value of μ when the ray is horizontal is equal to the sine of angle of incidence of the ray on the bottom of the layer, it is possible to deduce the density necessary to return the ray incident at any given angle. This will be of value in the later discussion. In the case of Rome (25·4 m) its direction of propagation is inclined at an angle of 70° to the magnetic meridian. Unfortunately this station has recently changed its wavelength to 80 m, so that no further observation on it is possible. As a substitute Aranjuez is used, but for various reasons this is less satisfactory.

A further study of these results has led to a suggestion which is put forward with considerable reserve, as it is in violent opposition to many accepted ideas, but which at the same time seems to require further investigation. It will be noticed in the report for the 15th October that there appeared in the course of the cycle to be complete and rather abrupt disappearance of one component without appreciable change in the other, though a few minutes previously they had been equal. Now it has been argued that the difference between the ray paths and equivalent maximum heights is very small, in which case it seems difficult to account for this effect merely by differential absorption, since this would have to be so abrupt as to be practically discontinuous. Also this is not an isolated case of this phenomenon. It has occurred fairly frequently; so much so that the appearance of the steady circle may almost be regarded as the preliminary warning of a fade-out. It can therefore hardly be a special accidental occurrence.

The suggested explanation is that both rays were reaching nearly to the top of the layer, and that a slight decrease in density caused first one and then the other to pass through and be lost. A corresponding slight increase then brought them back again. Again, on one occasion when Zeesen was showing behaviour of this type the set was tuned in to Rome. This station was found to be giving a large, steady ellipse in the true direction, suggesting that only one component was surviving. Now on examining the curves in Fig. 2 it will be seen that the separation of the rays for Rome is slightly greater than for Zeesen, so that it is conceivable that a state of affairs just sufficient to return both the Zeesen components was only able to return one from Rome. Both Rome and Aranjuez tend to show this steady form rather more frequently than Zeesen does.

If this is the case one is led to the conclusion that the "effective" ray is that one which has just been turned horizontal by the time it reaches the top of the layer, and if this is so it is not inconceivable that it may have a horizontal path of appreciable length along the top of the layer. The great objection to this is that it demands much more steeply downcoming rays than are usually accepted; this point will be discussed more fully in Part 2 of the paper.

The above statement may be expressed more rigidly as follows. At the top of the F layer the rate of increase of the electric gradient must diminish. Now the curvature of the path is proportional to this rate of change; so that under these conditions the maximum curvature of the path would not be at its highest point, which would therefore have a flattened top, even if it were not strictly horizontal except at the apex. The ray would thus preserve its individuality, and also over this portion of the path would probably suffer less loss by multiple refraction, owing to the slow rate of change of the gradient.

From this idea there also follows a further suggestion

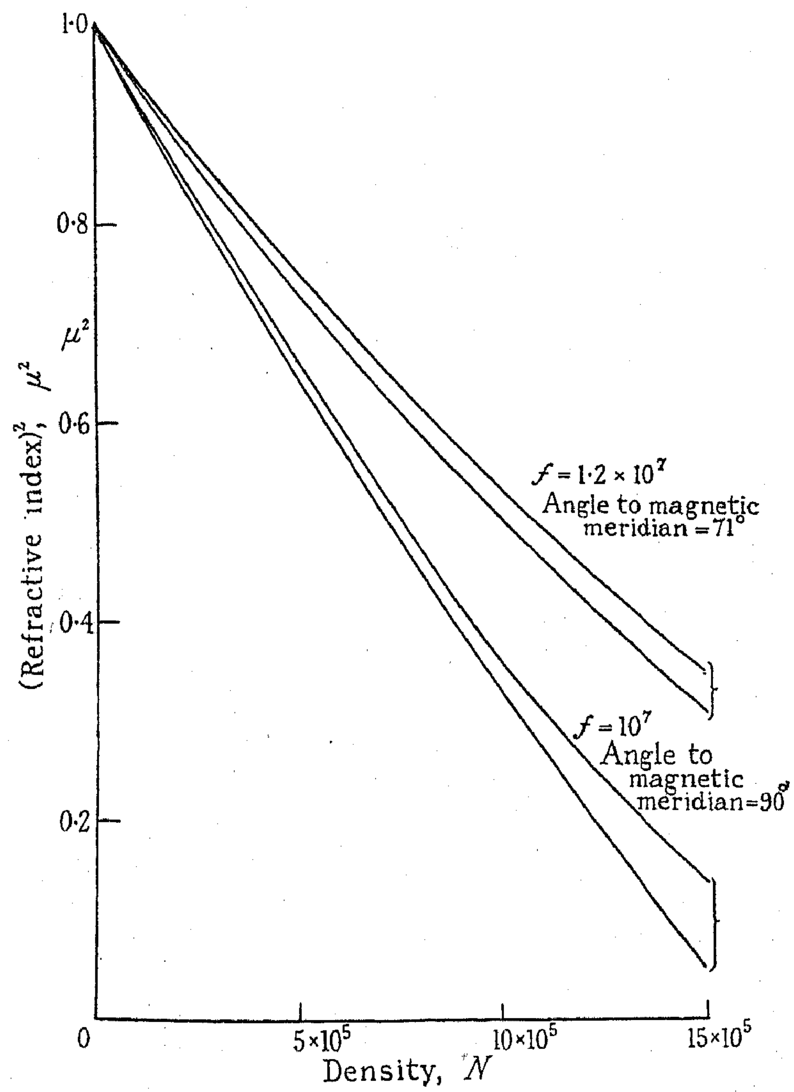


FIG. 2.

dealing with the observed facts of range. Although it is difficult to give exact figures, it will probably be admitted that the working range shows a rapid increase in the wavelength range between perhaps 80 and 50 m which is not paralleled either for corresponding increases or decreases of these figures. Now, as the wavelength increases the ionization required to deflect it decreases, i.e. if the ray is to be turned horizontal at the top of the layer the angle of incidence must decrease as the wavelength increases. A limit will eventually be reached with increasing wavelength at which, even with very low angles of incidence, the ray will have been turned horizontal before it has completely penetrated the layer, and will therefore be returned at once and only propagated by a larger number of multiple reflections, the loss at each of which would cause a great increase in the

apparent attenuation. It is suggested that this is the factor which determines the practical upper limit of wavelength for long-distance propagation. It is appreciated that from an energy standpoint this theory presents extreme difficulties, but the results obtained, especially in Part 2, are so definite that they must be faced.

On a few occasions Zeesen and Bandoeng have been working simultaneously and the comparison has been interesting. The most striking fact has been the strong similarity between their behaviours, in fact on a behaviour characteristic alone it would often be difficult to decide which one was observing. In one particular case when Zeesen gave its "circle and fade out" the set was rapidly tuned in to Bandoeng. There was here no actual fade-out but only the broadening and steadying of the ellipse which is generally regarded as its precursor. Now Bandoeng is roughly twelve times as far away as Zeesen, so that their close similarity is remarkable and one cannot help wondering whether, over the common portion of the distance, their ray paths are very close together. (Their geographic bearings at Slough are the same.) The principal distinctive features of Bandoeng are that the variations are slightly more rapid than those of Zeesen, and that there is a greater tendency to pulses of the type (4) on page 231.

We now come to another form of sequential effect which has been observed recently. Regular observations have now been in progress for about four months—though occasional ones had been taken for some time previously—and it is becoming clear that there are indications of seasonal effects. During the summer months it was frequently found that reception, though possibly weak, was so steady as to be very uninteresting from an analytical point of view. In the autumn this steadiness was replaced by behaviour of the type discussed above, though there was no abrupt transition. During November, however, a new type appeared of a much more irregular nature and more difficult to analyse. In this type the signal will show a large and fairly steady ellipse for a time, and this will be succeeded by violent and apparently irregular oscillations. It will then drop suddenly to 5 or 10 per cent of its intensity and give an ellipse which often appears to be very steady, though it is too small for accurate observation. It will then rapidly increase again, and may repeat such behaviour. Each phase lasts two or three minutes. In view of the fact that this type of behaviour is of comparatively recent occurrence it has not been possible to examine it in detail, especially as its rapid variations make observation difficult.

Determination of the Resultant Polarization.

From the fact that the cathode-ray set is in essence a direction-finder it follows that the direction of rotation of the spot forming the ellipse is the same as the direction of rotation of the resultant vector in the electric field. Hence, if the direction of rotation of the spot can be determined, the sense of the field polarization is known. To do this the h.t. supply lead to the tube is passed through a coil which forms part of an oscillator at a frequency of about 15 000 cycles per sec. This superposes a small e.m.f. of this frequency on the h.t. supply which, if the frequencies are exactly in an integral ratio (the working frequency of the main low-frequency amplifiers being 2·5 kilocycles per sec.) causes a corresponding number of prominences to appear on the circle or ellipse described by the spot, which in fact looks rather like a cog-wheel with 6 teeth. When the frequencies are in exact ratio these prominences appear stationary on the tube. If the impulsing frequency be now slightly reduced they will appear to move round in the same direction as the rotation of the spot; if it be increased they appear to move in the opposite direction. It is thus possible to determine the direction of rotation of the spot. In actual working, as the frequency adjustment is very fine it is usually impossible to hold the pattern stationary for any appreciable time, owing to slight creeps in the various oscillators; and the best method of operation is to vary the impulsing condenser through this point and notice the direction in which reversal of the rotation takes place. After some experience this becomes quite easy and definite on a steady carrier wave and reasonably workable on low-speed pure continuous-wave Morse. On interrupted-continuous-wave morse it is much more difficult owing to the blurring of the spot by the range of frequencies which can get through the amplifier, and on high-speed automatic sending it is only workable in the case of a master-controlled transmitter, since otherwise there is no definite relation between the phasing of successive signals, and the prominences would jump about irregularly owing to the varying phase relation. Difficulty also arises on high-speed Morse, owing to the stroboscopic effect.

This device has been working for only a week or two but has given very striking results. It is evident that both directions of rotation are present, since the resultant rotation, which is that of the greater of the two components, has been found to vary, being sometimes left-handed and sometimes right-handed. There are signs that there is a slight preponderance of left-hand, especially in the steadier states, but owing to the seasonal effects mentioned above these steady states have been rare since the device was installed. This, in fact, appears likely to be a cause of considerable delay in the experiments, since, in order to elucidate some particular point requiring reception of a certain type, it may be necessary to wait a long time before such a type occurs. One fact, however, stands out very prominently. It has been pointed out that all signals, whether varying rapidly or slowly, frequently assume the straight-line form or appear to pass through it.

In the case of rapid variations this may occur several times a minute. If the polarization be examined under these conditions it is quite definite that on the majority of these occasions there is no change in the direction of rotation. Occasionally it does occur—a very rough estimate might be on 10 per cent of the straight-line forms—but on the steadier occasions especially it may be very infrequent, in fact almost absent. Also, no case has yet been observed of change of rotation taking place except when passing through the straight-line form.

Now, from the fact that the straight line is itself caused by the two components of equal intensity, these results indicate that there must be a definite tendency of the two components to have equal values, and that

they oscillate about this as a normal condition. If they were merely of about the same average value and both varying independently, one would expect a change in the direction of rotation as they passed through equal values to be the rule rather than the exception, as it undoubtedly is. Since this device was installed no cases similar to that of the 15th October have occurred, and on the majority of occasions the signals have been of the rapidly varying type, but it is hoped to examine the former type when occasion offers.

Multiple Reflections.

So far with a few exceptions it has been tacitly assumed that only one downcoming ray is present, the combination of the two components being treated as one. Of course the majority of the transmissions studied have been from distances of the order of 1 000 km, at which multiple reflection would not be expected, but this does not include the cases of Saigon and Bandoeng.

When the experiments were started it was definitely expected that Zeesen and Bandoeng would show marked differences due to this cause, and their apparent similarity came as a great surprise.

If several reflections are present of comparable amplitude their path differences must be very large compared with the critical distance of 1 wavelength, and one would expect this to show up in the form of erratic and extremely rapid variations. On the other hand, two facts indicate that they may be present to a small extent. The first is the appearance of the more rapid subsidiary pulses referred to on page 231, and the other is that in the cases of "fade out" mentioned there was often not total extinction of the signal, but a residuum of a few per cent of the previous value. Both of these may be covered by the existence of multiple reflections of small intensity. It is, of course, possible that with long-distance transmission the strong, comparatively steady, signals are the exception rather than the rule, and that the greater part of the transmission consists of the small residuals. Further reference is made to this later.

Special Results.

Two other interesting facts which have been noted are worth recording although they have no very direct bearing on the main lines of this paper.

(*a*) *Short Distances.*—On a few occasions G5SW (Chelmsford) on 25·2 m at a distance of 76 km from Slough has been received. The signals are usually very weak but appear to be entirely different from these at longer distances. The ellipse is in a state of violent irregular oscillation, and frequently two, apparently interlaced, are observed simultaneously. This seems to be in accordance with the scattering effect, the double ellipse being due to complete change in the path of transmission in a period less than that of the residual fluorescence of the tube.

(*b*) *Magnetic Storms.*—On the 29th October Zeesen was specially noted in the log as being in a very unsteady state at 1330 G.C.T., the ellipse actually at one time making 10 revolutions in the same direction in 6 seconds. The majority of other stations between 25 and 32 m were also unusually disturbed. It was found later that there was a magnetic storm on that day. The effect may have been a coincidence, as no repetition has occurred so far.

Theoretical Considerations.

In connection with this work it was suggested by Mr. Barfield that if the angle of incidence were very high the effect of reflection from an imperfect conductor would tend to accentuate this ellipse, owing to the change in phase of the reflected component of the vertical electric force being greater than that of the horizontal.

The following calculation was therefore made from figures supplied by him.*

Let E_v = vertical component of the electric field.
E_h = horizontal component of the electric field.

Then in the case of a circularly polarized wave

$$|E_v| = |E_h|$$

Also let β = e.m.f. induced in a vertical coil in the plane of propagation.
α = e.m.f. in a vertical coil at right angles to this.

Then
$$\beta \propto E_v(1 + \rho_v)$$
$$\alpha \propto E_h(1 - \rho_h) \cos\theta$$

θ being the angle of incidence.

Therefore in this case

$$\frac{\alpha}{\beta} = \frac{(1 - \rho_h)\cos\theta}{1 + \rho_v}$$

where $\rho_h = \dfrac{\cos\theta - \sqrt{k'}}{\cos\theta + \sqrt{k'}}$ and $\rho_v = \dfrac{\sqrt{k'}\cos\theta - 1}{\sqrt{k'}\cos\theta + 1}$

$k' = \kappa - 2j\sigma/f$ in the usual notation

Taking $\kappa = 10$, $\sigma = 1\cdot5 \times 10^8$, $f = 10^7$, we get the following results for a circularly polarized arriving wave:—

θ	85°	80°	75°	70°	60°	50°
α/β	0·25(24°)	0·33(17°)	0·405(13°)	0·47(10°)	0·605(6°)	0·73(4°)

Now since the phase change is, in general, small, α/β equals, to the first order, the ratio of axes of the

* See Reference (9).

ellipse (the maximum error arising from this assumption being 8 per cent). Hence we get:—

Angle of incidence	85°	80°	75°	70°	60°	50°
Ratio of axes (imperfect conductor)	0·25	0·33	0·405	0·47	0·605	0·73
Ratio of axes (perfect conductor) = $\cos\theta$ ..	0·087	0·173	0·258	0·342	0·5	0·643
Broadening ratio due to imperfect conduction ..	2·87	1·91	1·57	1·37	1·21	1·13

It will be seen at once that this is not sufficient to give the nearly circular figures mentioned in the paper, if the angle of incidence is high.

A certain amount of information can also be derived from a consideration of the approximately known heights and densities of the ionized layers. It will be assumed that there are two layers, the lower at a height of 100 km with a maximum density of 2×10^5 electrons per cm^3, and the upper at a height of 300 km with a maximum density of 8×10^5 to 10×10^5 electrons per cm^3.

From these data it is possible to calculate the ranges of rays reflected at these layers for various angles of incidence, and the results are given in Table 2, together with the appropriate values of μ^2.

TABLE 2.

Layer at 100 km			Layer at 300 km		
Angle of incidence	Range	μ^2	Angle of incidence	Range	μ^2
	km			km	
90°	2 240	0·97	90°	3 800	0·915
85°	1 400	0·965	85°	2 800	0·905
80°	930	0·94	80°	2 200	0·885
75°	665	0·905	70°	1 380	0·8
70°	515	0·86	60°	930	0·68
65°	420	0·79	40°	470	0·38

Now from the curves in Fig. 2 it will be seen that for Zeesen the value of μ^2 at a density of 2×10^5 is about 0·88 and at a density of 8×10^5 to 10×10^5 it is 0·46 to 0·34. Again, the distance of Zeesen is 920 km, so that a second reflection from the lower layer would come down at an angle of about 67° and from the upper layer at an angle of 40°.

Comparing these with the critical values of μ^2 it appears that a second reflection from either layer is extremely unlikely, especially since the values for N at the top of each layer are probably rather on the high side. Moreover, if a second reflection did survive it is difficult to see why a first reflection from Eindhoven ($\lambda = 31{\cdot}28$ m; distance 580 km) should not also survive, whereas it is a matter of common experience over several years that the latter station is usually inaudible at Slough during the day-time.

Hence we are driven to the conclusion that only first reflections survive with angles of incidence of 80° and 60° respectively, and we are immediately faced with the difficulty that, apart from any possible measurement of lower angles of incidence, these values are not sufficient to give the wide ellipses actually observed.

The question of a long-distance station such as Bandoeng will now be treated. Here the distance is 12 000 km (approx.). Assuming multiple reflection, the first signal from the lower layer to reach Slough would have required 6 spans, i.e. 5 intermediate reflections at the earth's surface, and the first from the upper layer 3 intermediate reflections. Their angles of incidence would be 89° and 86° respectively. Now it may be admitted from the observations that Bandoeng has never given almost perfect circles like Zeesen, but still the ellipses have been at least with an axis ratio of 2 : 1, which seems entirely unobtainable with such low earth angles, whereas an angle of incidence of 70° would involve the 23rd reflection from the lower layer and the 15th from the upper. Even allowing for almost perfect reflection at layer and earth these figures seem excessive.

Part 2. ANGLE OF INCIDENCE.

In Part 1 only incidental reference has been made to the angle of incidence and no question as to its magnitude has been raised. Actually, of course, this is a most important question, both practically and theoretically. On examining the evidence derived from different sources there at once appear to be very serious contradictions. The case for the large angle (> 70°) has been stated by T. L. Eckersley,* and is in agreement with general practical experience. As soon as the experiments for the present paper were started, however, one of the first things noticed was the large intensities given on the tube by the horizontally polarized electric force. It will be remembered in many cases, especially on Zeesen, that reference has been made to a "circle," and, while the geometry of the tube at present in use is not good enough to determine the perfect circularity, there is no doubt that in many cases the e.m.f. generated by the horizontal component of electric force is not much less than that of the vertical.

PRACTICAL INVESTIGATION.

As a result of the special system of reception employed it has been found possible to construct a set consisting of a vertical aerial and a coil, each with its associated receiver which can be worked on the same station at the same time without mutual interference and which can, moreover, be worked simultaneously with the cathode-ray set, the distance between them being only 15 ft. The aerial-coil set consists of a vertical aerial about 8 ft. high mounted within a foot or so of a coil which can rotate about a vertical axis. The aerial itself can be moved parallel to itself over an arc of about 90°

* See Reference (8).

about the coil axis, the primary object of this being to allow the coil to be set at any bearing without mechanically fouling the aerial. With the system of reception involved, the mutual induction between the coil and aerial is of minor importance. The two sets are connected to amplifiers whose output is rectified and passed through two moving-coil relays fitted with mirrors to act as oscillographs and giving traces on a common band of travelling sensitized paper. The period of these relays is about $\frac{1}{8}$ sec., which is sufficient to cope with the majority of the fades.

Actually a form of this apparatus was constructed before the cathode-ray outfit, and a considerable number of readings were taken with it. These appeared to show at times very small angles of incidence (down to 30°); but the set was only of a temporary nature, and after some time a slight doubt arose as to its instrumental reliability. Consequently all these readings were held up pending confirmation or otherwise while the set was totally reconstructed. This reconstruction is now complete and has enabled a fresh series of observations to be taken which appear to confirm the previous ones. It had been intended that they should form the first part of an extended investigation on the subject, but two things have occurred to interrupt this. First, it has been found necessary to discontinue the observations in favour of another problem of more immediate practical importance, and secondly the acceptance of another appointment by the author is likely to cause a temporary dislocation of the work, although it is hoped to carry it on again under the new conditions. The results already obtained, though incomplete, appear too interesting for their publication to be indefinitely postponed, and it is therefore proposed to summarize them in this Part of the paper, although final decisions must be deferred until later.

The results in Part 1 of the paper were specially taken under conditions likely to illustrate the magneto-ionic effects in the most marked way. These results appeared to point, as a side issue, to smaller angles of incidence than had been expected, but it was thought necessary to vary the conditions of reception again for the study of the latter problem, in order to maintain the principle of working under the best conditions for the particular point at issue, rather than under those of actual practice. The chief differences are as follows:—

(*a*) At a distance of 1 000 km and a layer height of, say, 250 km, as used in the previous experiments, the maximum angle of incidence on purely geometrical grounds is 66°. To avoid this limitation it is necessary to work at greater distances, so that if unexpectedly small angles of incidence are still obtained they can be definitely ascribed to physical and not geometrical causes.

(*b*) On the other hand, any apparatus based on the aerial-coil principle involves a cosine law and is therefore insensitive at high angles of incidence. The frequency should therefore be chosen to keep this angle as low as possible.

(*c*) Now whatever be the detailed law of propagation it seems almost certain that the lower the frequency the less ionization is required to bend the ray through a given angle, hence if small angles of incidence are required it seems probable that they would be much more likely to be obtained on lower frequencies. Moreover, in the frequency range under consideration the magneto-ionic separation increases as the frequency decreases, so that a simplification might be expected on these grounds. This is limited by the practical fact that at frequencies less than about 4 megacycles per sec. the conditions of transmission appear to change in that they become of much less value for long-distance propagation, thus placing a lower limit on the permissible frequency range.

Taking all these factors into account, the station selected for observation was Moscow on 6 megacycles per sec., its distance from Slough being 2 500 km.

First Series of Experiments.

These were undertaken largely with the idea of examining the problem generally in order to derive useful suggestions for further progress. They consisted in general of a total observation period of 60 sec. For the first 30 sec. the coil was set in the plane of propagation and then abruptly turned at right angles to this for the remaining half-minute. With the apparatus now used this has no effect on the adjustments or calibration. The results of such a test are shown in Figs. 3(*a*) and 3(*b*), (*a*) being with the coil in the plane of propagation (referred to in future as the "direct" position), and (*b*) with the coil at right angles to this (called the "cross" position).

Many interesting facts are deducible. On examining the (*a*) position it will be seen that the two curves follow one another in general direction exceedingly closely. The aerial reading is in every case the lower curve, and the gains are so adjusted as to give equal deflections for a wave arriving horizontally. Moreover, the ratio of the two readings keeps very closely constant throughout all the fades at a value of $0 \cdot 45$. From these it follows that the arriving wave consisted of a single ray at a ray angle of arc cos $0 \cdot 45 = 62°$. It is at this point interesting to compare this result with Fig. 8(*a*), where the correspondence in general shape is just as good but the difference between the maximum and minimum coil/aerial ratios shows the presence of a second wave, and with Fig. 10, where the displacement of the minima shows a third also (see Appendix II).

In Fig. 3(*b*) it will be noted that while the two curves still follow one another closely, especially when they are both large, the correspondence is less good when they are small. Now for a coil in any given direction a fade can be due to two separate causes. It can either be a general intensity fade or a phase fade due to interference between two components. On the cathode-ray direction-finding system the first of these is shown by a change of size of the ellipse without change of direction; the second by a rotation of the ellipse without change of size.

These two systems of fades have entirely different effects on the relative values of the vertically and horizontally polarized components, the latter of which

is the one given by the coil in the "cross" position. For a pure intensity fade it is evident that both axes of the ellipse will increase and diminish together, giving in-phase traces on the aerial-"crossed" coil trace. If, however, it is a phase fade and the ellipse rotates, the amplitudes of the aerial-"crossed" coil trace will be definitely 180° out of phase. Inspection of Fig. 3(*b*) shows the former of these two alternatives for most of the time, i.e. the main downcoming component consists of a wave suffering pronounced intensity fading and no phase fading. The fact that no phase fading is present suggests that only one of the magneto-ionic components is being returned, and it eliminates the possibility of the signal consisting of a bunch of rays separated by very small angles, since the components of such a bunch would have travelled by different paths and would therefore almost certainly cause phase-fades as the paths varied. This is in agreement with the curves in Fig. 4,

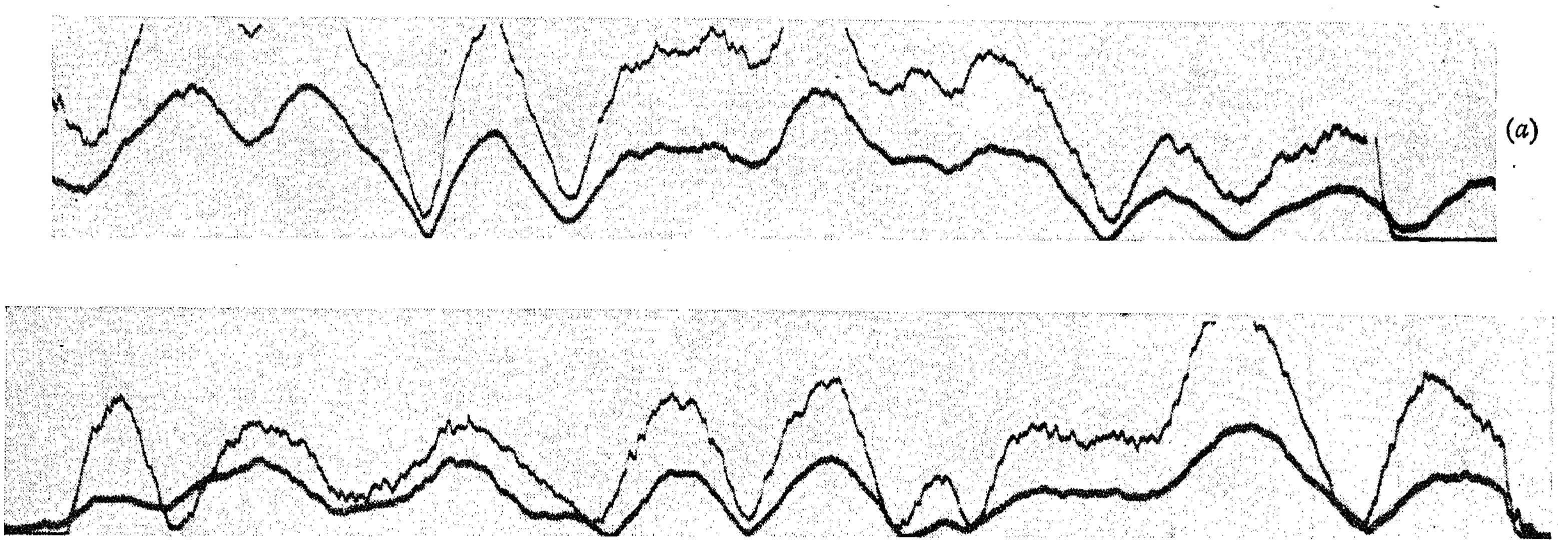


FIG. 3.

(*a*) Coil in "direct" position. This shows close agreement in shape and ratio between coil and aerial curves.
(*b*) Coil in "cross" position. This shows the slight departures from correspondence at low intensities. It succeeds Fig. 3(*a*) immediately in time. Each exposure 20 sec.

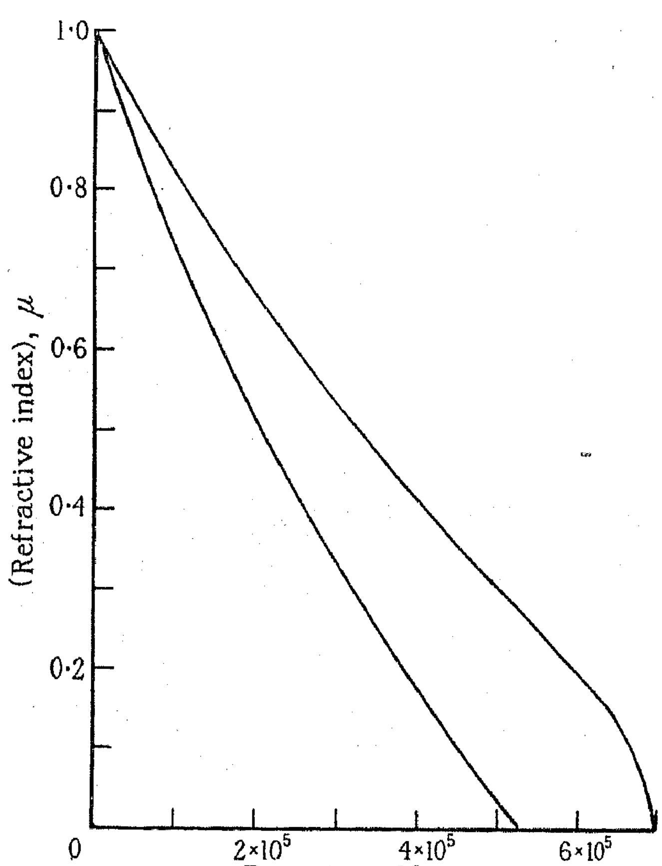


FIG. 4.—(N, μ) curves for 6 megacycles per sec. (Moscow).

where it is shown that for high values of μ (corresponding to high ray angles) the separation is large.

If this be the case the downcoming ray will consist of a single circularly-polarized component. It has been hoped to check this by a polarization measurement on the cathode-ray direction-finding system; but the sensitivity of the latter is considerably lower than that of the aerial-coil set, and while nearly perfect circles have frequently been observed on it they have been too small to admit of polarization analysis, for which a figure of reasonable size is required. The idea can, however, be confirmed in another way.

With the coil in the "cross" position the e.m.f. induced in it is $E_h \sin\theta$, where E_h is the horizontal component of electric force and θ the ray angle.

With the coil in the "direct" position the corresponding e.m.f. is E_v in the coil and $E_v \cos\theta$ in the aerial.

Now if the ray is a single circularly-polarized one $E_v = E_h$. Therefore

$$\text{Ratio } \frac{\text{Aerial}}{\text{Direct coil}} = \cos\theta, \quad \text{and} \quad \frac{\text{Aerial}}{\text{Cross coil}} = \cot\theta$$

In this case the determination of $\cos\theta$ from Fig. 3(*a*) and of $\cot\theta$ from Fig. 3(*b*) gives substantially the same angle, thus confirming the assumption that the main ray is circularly polarized and has a ray angle of 62°.

Reference should here be made to Fig. 13, which shows the aerial-"cross coil" trace from WND (Laurenceville) on 13 390 kilocycles per sec. Here the difference in phase between the two curves is much greater than in Fig. 3(*b*), indicating that both components were present in the main ray.

The small departures from uniformity in Fig. 3(*b*) when signals are small suggest that there are smaller components incident at higher angles of incidence which are only big enough to indicate their presence when the main

ray is at a fade minimum. Cases of this will be found to occur frequently. Again, the fact that these rays do cause out-of-phase movements suggests that they are subject to phase fading, which is again in agreement with theory, since at high angles of incidence the separation of the two values of μ is much smaller and both would be more likely to be returned.

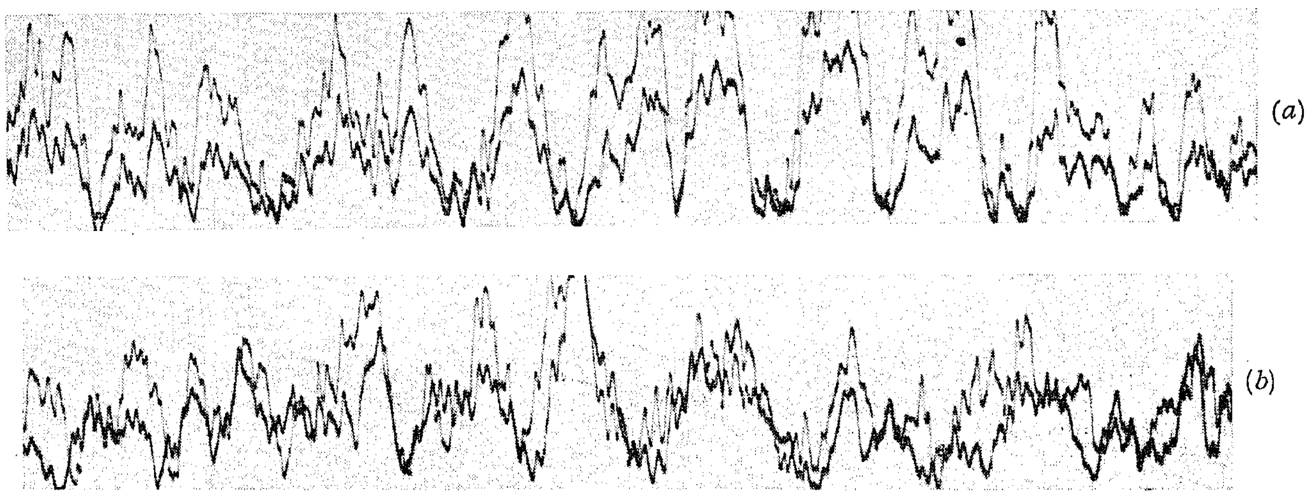


FIG. 5.
(a) Coil in "direct" position. Small, rapid oscillation imposed.
(b) Coil in "cross" position. Note slight occasional anti-phase movements.

Owing to slight departures from linearity in the scales of the oscillographs, it is necessary to measure and correct all the curves if numerical results are required. (In the original traces the scale given by the engraved cylindrical lens of the oscillograph shows up clearly, but it has been lost in reproduction.)

As the ratio appeared to be about 0·5, some observations were taken of which Fig. 11 is an example, with the sensitivity of the "coil" oscillograph reduced to one-half that of the aerial oscillograph. If the ray angle is exactly 60° the curves should now be absolutely coincident, and Fig. 11 shows how nearly this is realized.

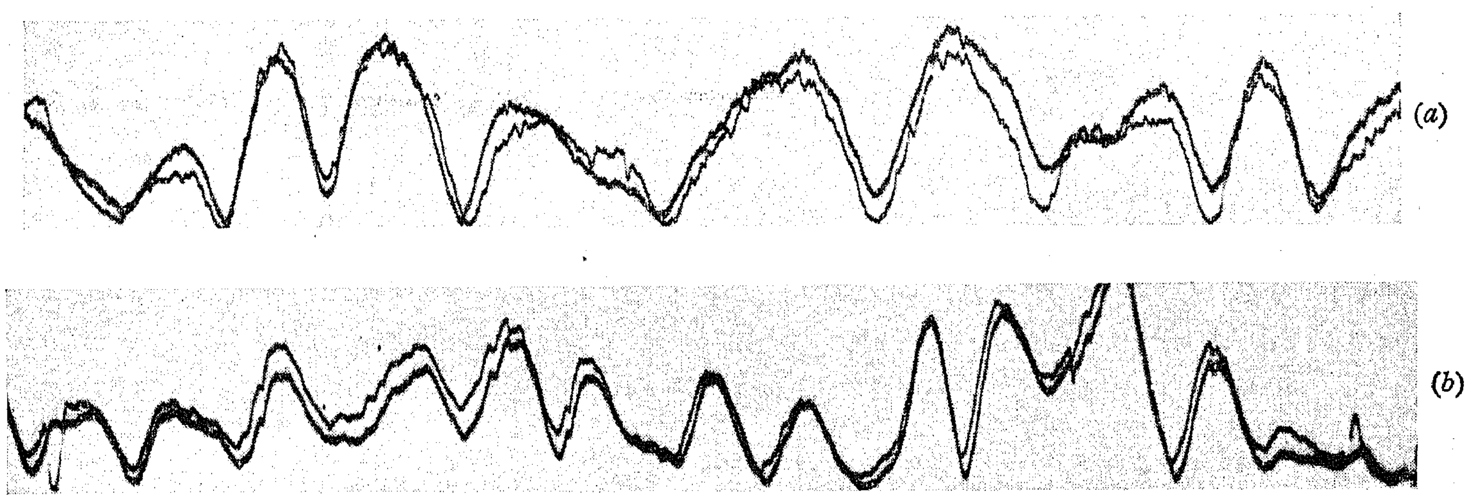


FIG. 6.
(a) Coil in "direct" position. Aerial and coil intensities nearly equal, showing small earth-angle.
(b) Same as (a) but taken 30 mins. later.

Figs. 5(a) and 5(b) show a similar effect but with a small high-frequency phase superposed, and is interesting from the fact that in some parts of 5(b) the anti-phase movement is more marked.

At this stage of the work (several other similar curves, which are not reproduced, having been obtained) the procedure was altered. It was felt that probably as much information as was obtainable had been obtained from the comparison of "direct" and "cross" coil readings, and that attention should now be given to sequential effects. Readings were therefore taken at an interval of 30 min. with the coil in the "direct" position, and are shown in Figs. 6(a) and 6(b). Here the interesting fact is that on this occasion the ray appears to have a very high angle of incidence—too large to calculate accurately. The idea was then carried further by taking a series of "direct" readings every 15 minutes over a period of 2 hours. These are given in Figs. 7 and 8. They vary in the degree to which they can be analysed; but the following comments have been deduced from them by inspection and calculation.

Figs. 7(a) and 7(b). Times 1535 and 1553 G.M.T., 29th April, 1932. Very weak signals; full gain on amplifier. Occasional signs of a fairly low angle of incidence, but signal probably mostly composed of small high-angle rays of comparable intensity.

Fig. 7(c). 1608 G.M.T. Same amplifier gain. Most prominent ray at a high angle of incidence; weaker

components at lower angle; propagation not regular enough for systematic analysis.

Fig. 7(*d*). 1623 G.M.T. General characteristics similar to Fig. 7(*c*) but with rapid fading which has been noticed several times. The cause has not yet been traced.

Fig. 8(*a*). Here we get an example of systematic and rapid fading, with fairly strong signals, the amplifier being 13 decibels down on Fig. 7. Examination of the ratios at maximum and minimum shows that two rays were present, and the good correspondence in time of the minima that there were not more than two. Analysis suggests that there were two rays, one about 0·4 that of the other. Their ray angles are not easily separable but appear to be about 50° and 60°, and the variations are caused by phase fading between them.

Fig 8(*b*). Similar to the last, but gave much better results on analysis. Consists of two rays, E_1 at a ray angle of 60°, and E_2 at an angle of about 30° and a mean value 0·5 of E_1. Both have fade periods of about 6 sec., but they do not follow one another. The actual results are caused by phase interference between these rays.

Fig. 8(*c*). We again revert to the case in which a single high-angle ray is predominant.

Fig. 8(*d*). Seems to indicate a single ray coming down almost vertically. While there is no specific reason to suspect instrumental trouble, the result is so surprising that it is thought better to defer judgment in the hope of getting a similar effect on another occasion.

A further test was then made on the same lines over a period of 3 hours. The following are some of the analytical results obtained.

Fig. 9(*a*). 1608 G.M.T., 5th May, 1932. Two rays present, main one at about 60°, approx. five times as strong as one at lower angle. Rapid fading of both, but period 6 to 7 sec. Apparent changing transmission conditions.

Fig. 9(*b*). Ray at an angle of about 50° very predominant.

Fig. 9(*c*). Transmission conditions changing considerably. Analysis of small part gives main ray at 48°, second half its size at 55°.

Fig. 9(*d*). Main ray at 63°. Two smaller ones.

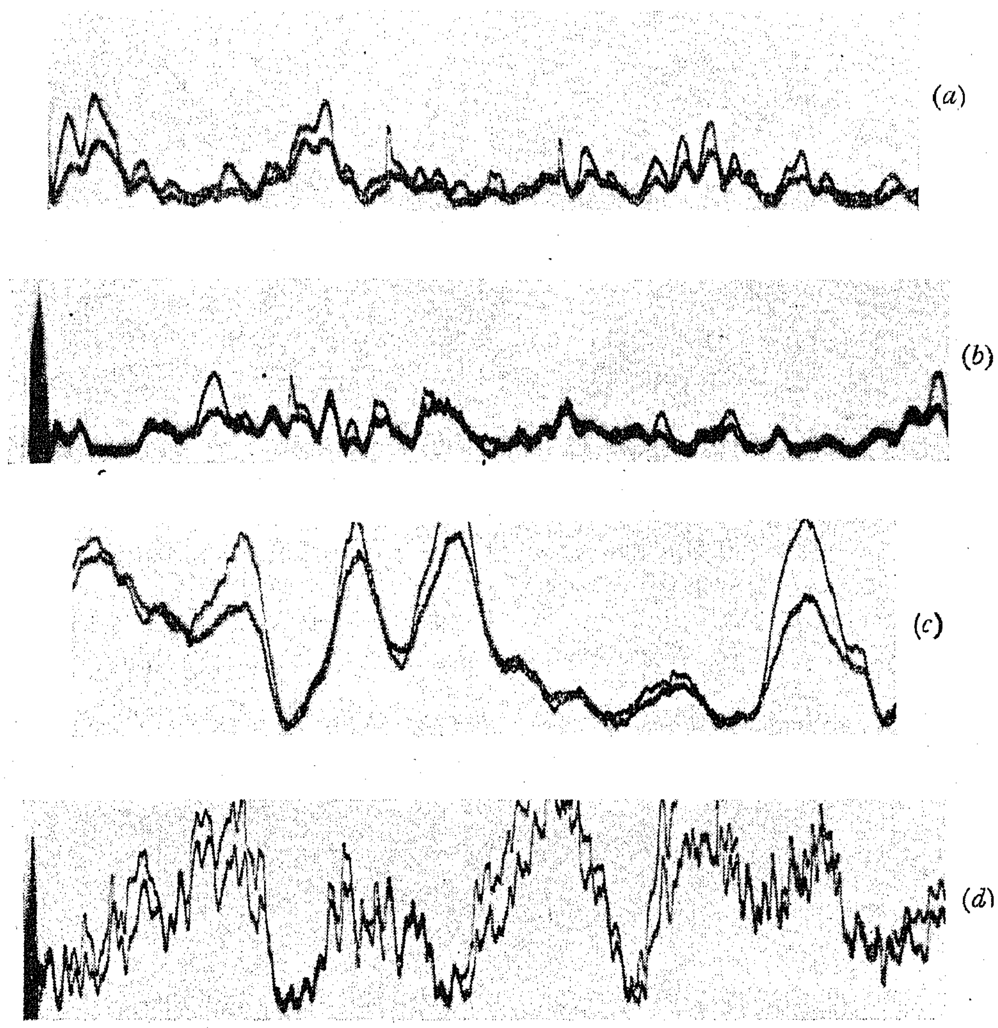


FIG. 7.—Observations taken on the 22nd April at intervals of about 15 mins. Each exposure 30 secs. duration. Time of commencement 1535 G.M.T.

SUPPRESSED-RAY SYSTEM.

The system employed up to this time was found to have one weak point. While it was fairly easy to determine by inspection the existence of one, two, or three rays, the analysis, except in the first case, presented some difficulty. To determine the magnitudes and ray angles of the components numerically, it is necessary to analyse a piece of the record covering a period of a few seconds. Such analysis involves the assumption of a certain degree of constancy or regularity of behaviour over this period. While, as in the case of Fig. 8(*a*),

this was found to be possible occasionally, in the great majority of cases it is not, and a new idea was brought forward to deal with it. This was based on the suppressed-ray idea and consisted in the fact that if one particular type of fade is caused by a ray at a certain angle the suppression of the ray at that angle should cause the disappearance of that particular fade.

Under ordinary conditions ray suppression is effected by tuning the coil and aerial and coupling them through a variable mutual inductance. They are then de-tuned until they are 180° apart in phase, and the coupling is varied until the required effect is obtained. The difficulty with this, especially at high frequencies, is the critical nature of the phase adjustment and the calibration of the mutual inductance in terms of angle of incidence. If, in addition, the change in mutual induction has any effect on the phase relation, anything in the nature of a rapid sweep of angle suppression becomes impossible.

Although employed on a coil and aerial instead of on two coils the apparatus was in essentials a cathode-ray direction-finding system, the vital principle of which is, of course, maintenance of the original phase relation through the frequency-change. It appeared possible, therefore, to leave the high-frequency circuits untouched and effect the necessary phase adjustment at the low frequency (2·5 kilocycles per sec.). This method would, moreover, get over the difficulty of reactions between the high-frequency circuits, which could, if necessary, be maintained at zero mutual induction throughout. The first method tried was, therefore, to join the grids of the final low-frequency amplifying valves and use the phase control which is a normal part of the low-frequency units. When the phases were thus balanced a mere alteration in the calibrated gain control of the amplifier belonging to the coil unit effected the necessary ray suppression at the appropriate angle.

This system was tried and found to work properly, but in actual operation rather severe difficulties arose. The first of these was that since the coil and aerial e.m.f.'s are normally at right angles, a further shift of 90° is required in the low-frequency units. The phase adjustment provided only gave much less than this, and greater shifts not only were instrumentally difficult but fundamentally tended to affect the intensities rather seriously.

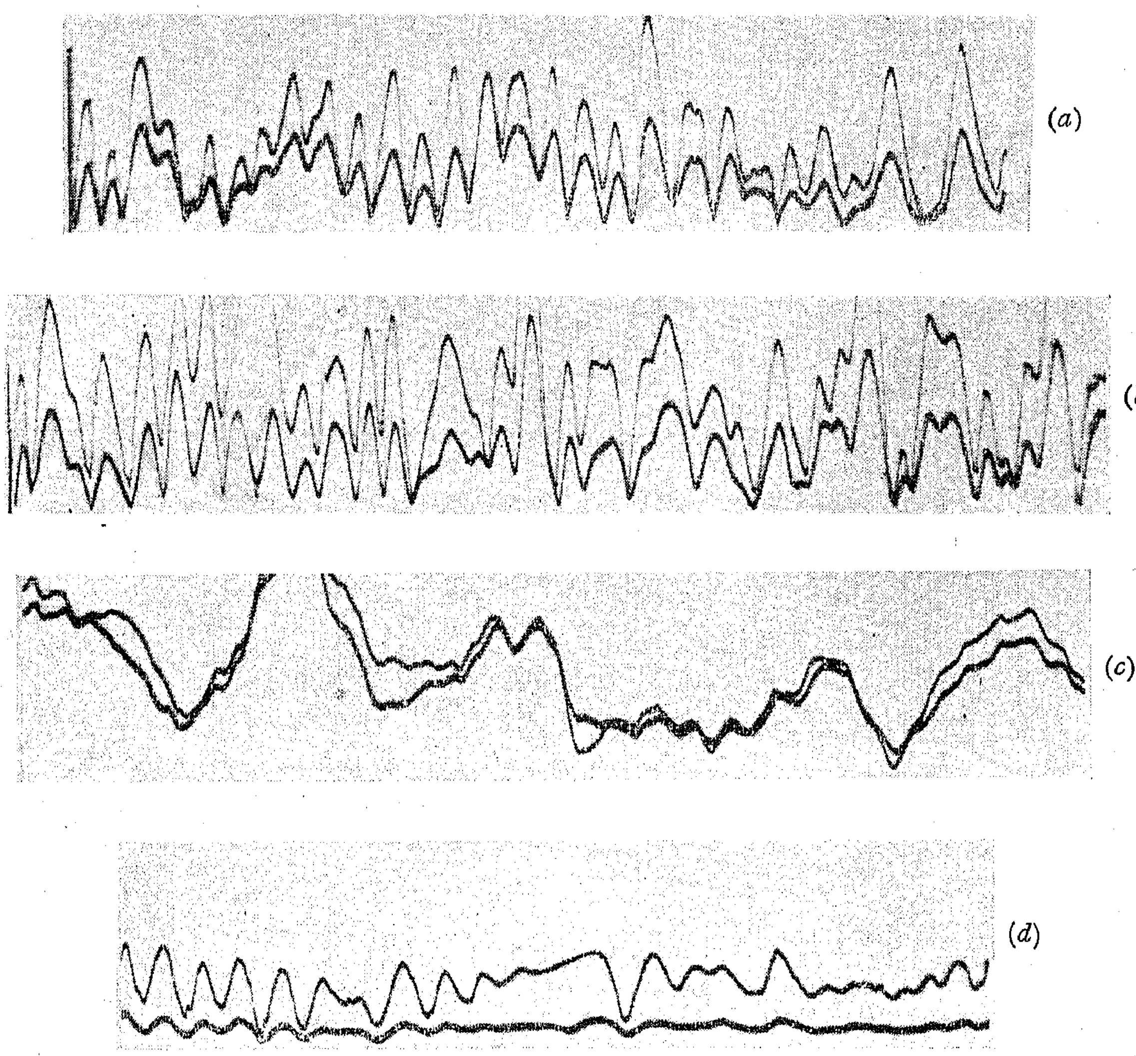


FIG. 8.—A continuation of Fig. 7. Note the surprising change in the nature of the arriving wave at intervals of only 15 mins.

The other problem was in connection with the calibration. The set must, of course, be calibrated on the exact wavelength used, and the normal method of doing this, as in the cathode-ray direction-finding system, is to reduce the gain of the amplifiers by cutting out one valve and then apply a strong signal from a local source set to the correct adjustment. While this is fairly easy in the case of the two identical units of a cathode-ray direction-finding set and also in the previous aerial-coil work where only intensities and not phases were involved,

for the ray suppression it was essential that the inductions into the coil and aerial systems should be completely independent and separately adjustable for both intensity and phase, the latter over considerable angles. This was actually achieved, but only at the price of considerable complication largely caused by small stray e.m.f.'s, since the two sets are only a few inches apart. It was therefore decided to adopt a third method which, while not absolutely sound theoretically, is sufficiently so to give results of considerable value and at the same time allow of very great simplification instrumentally.

This method is based on the following idea. It will be remembered that the high-frequency signal after being reduced to 2·5 kilocycles per sec. is rectified a second time and then passed through a d.c. instrument. The actual current through this instrument consists, of course, not of pure direct current but of half-wave pulses at 2·5 kilocycles per sec. which are integrated by the d.c. instrument. Consequently if the two d.c. outputs are connected in opposition with a bridge circuit as shown in Fig. 15, in order to obtain a balance in the instrument it is only necessary to equalize the amplitudes of the two outputs without paying any attention to the relative phases of the half-wave pulses. The set can consequently be adjusted and operated on an intensity basis only. For actual working a small portable transmitter is set up about 300 m away, thus giving a pure ground wave. It need not be exactly at the wavelength it is proposed to investigate. It is then tuned in and adjusted until the ground ray (in this case the total ray) is suppressed by operating the gain control on the aerial set, leaving the coil-set control at full gain. Without alteration to the adjustment the local check circuit is then tuned in and its couplings to aerial and coil are varied until the zero is again obtained on the microammeter. This local circuit is then ready for use as the reference circuit for the reception of a distant transmission, the portable transmitter being no longer required unless the frequency at which it is required to work is altered. When receiving a distant signal it is tuned in and adjusted in the same way by reference to the local check circuit, leaving the coil gain control at full gain as before. The suppression of a ray at any angle θ is then instantly obtained by bringing back the coil gain control from its full value 1 to the value of $\cos\theta$. In this way the whole range from 0 to 90° can be rapidly swept out.

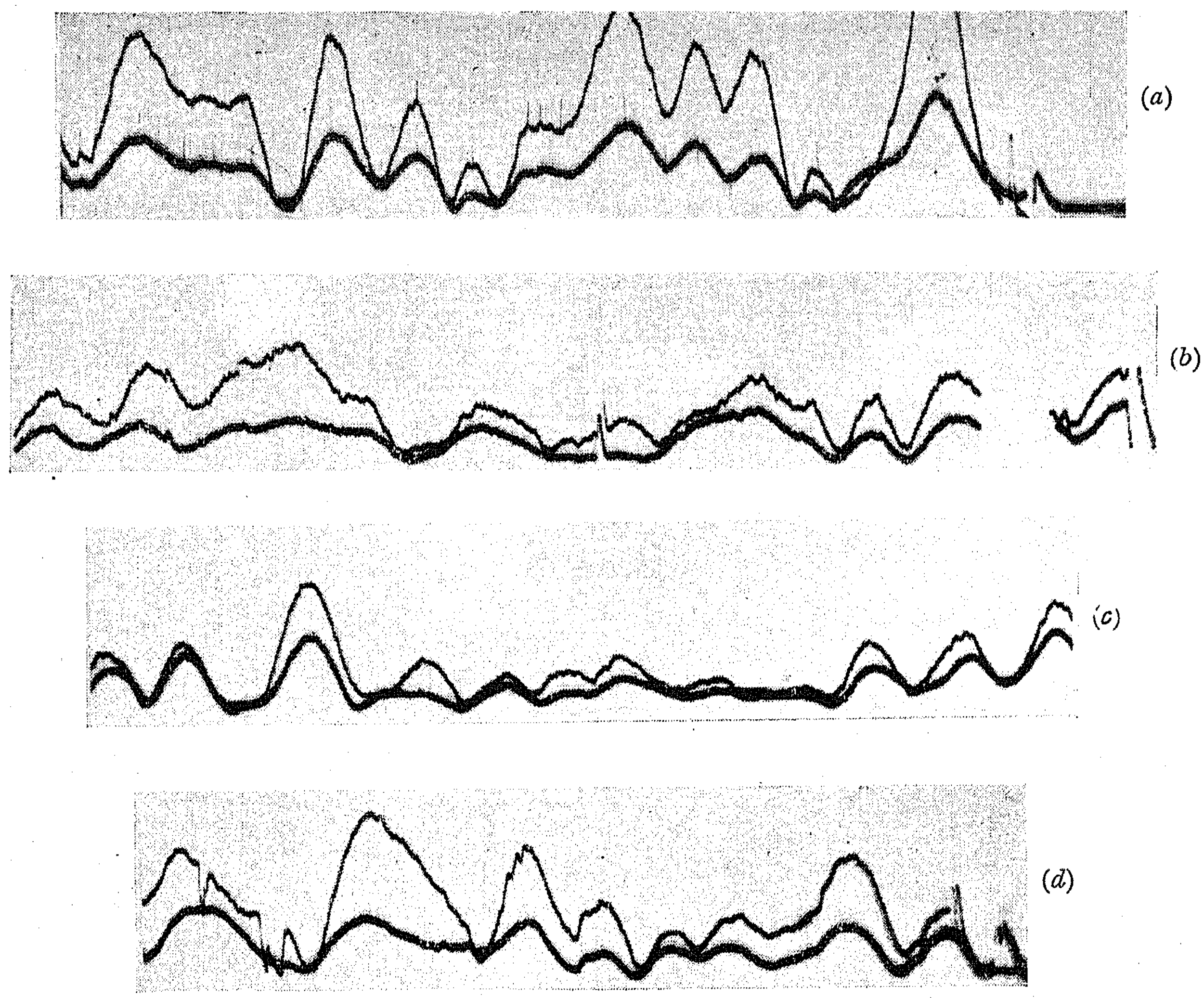


FIG. 9.—A test similar to Fig. 8, taken on the 29th April. Intervals between exposures 15 mins.; duration of each exposure 30 secs.

The second microammeter and oscillograph are retained in their normal position on the output of the aerial set as shown in the figure, so that the photographic trace shows simultaneously the aerial and suppressed-ray intensities. Direct instantaneous comparison between the two is thus possible, and the set is so wired that by the movement of a single switch it reverts directly to the normal aerial-coil system described in Part 1 of the paper which, while not so suitable for this purpose, has its own use, particularly in giving the relation between the normally and abnormally polarized fields by working in the "crossed coil" position.

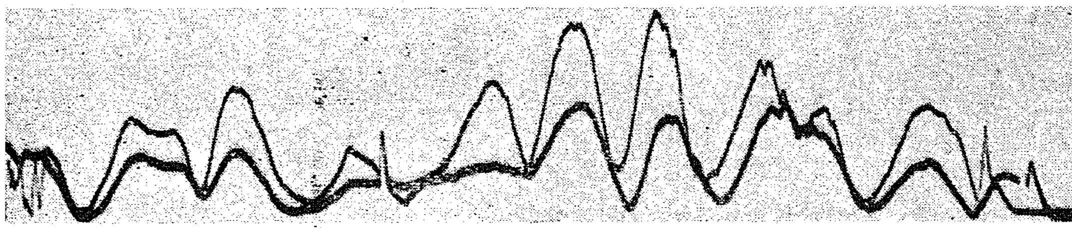


FIG. 10.—Somewhat similar to Fig. 3(*a*), but with marked displacement of minima, showing presence of a third wave.

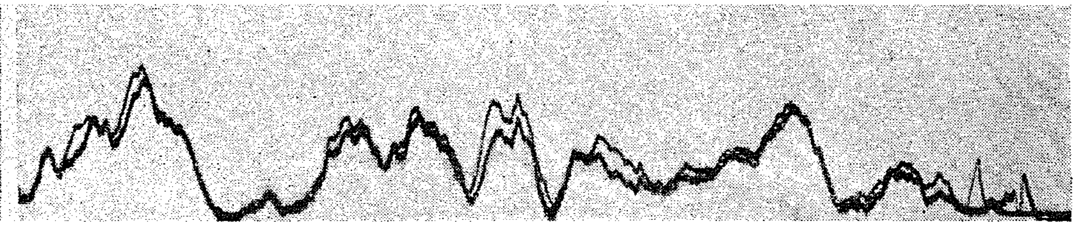


FIG. 11.—Similar to Fig. 3(*a*), but with sensitivity of coil receiver set to half that of aerial receiver. This shows the marked closeness of aerial/coil ratio to a value of 0·5.

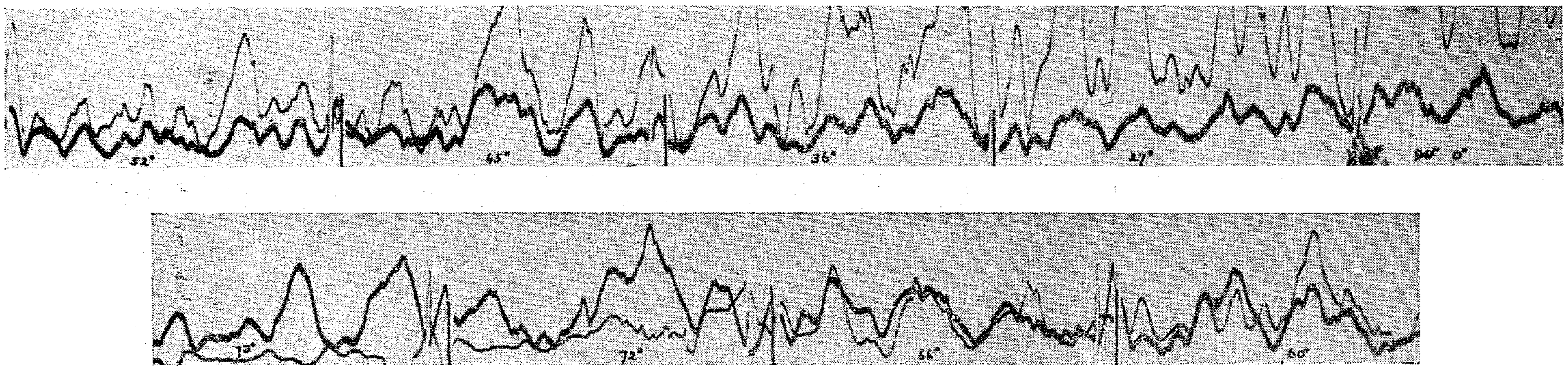


FIG. 12.—Suppressed-ray system. The figures in each section give the ray angle (complement of the angle of incidence) for which suppression is total.

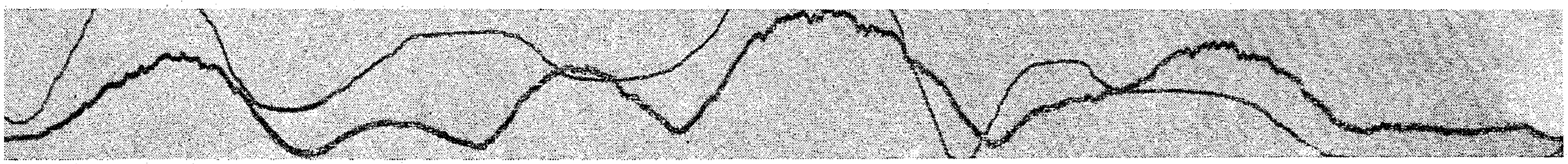


FIG. 13.—Aerial—" cross-coil " traces for WND (13 390 kilocycles per sec.).

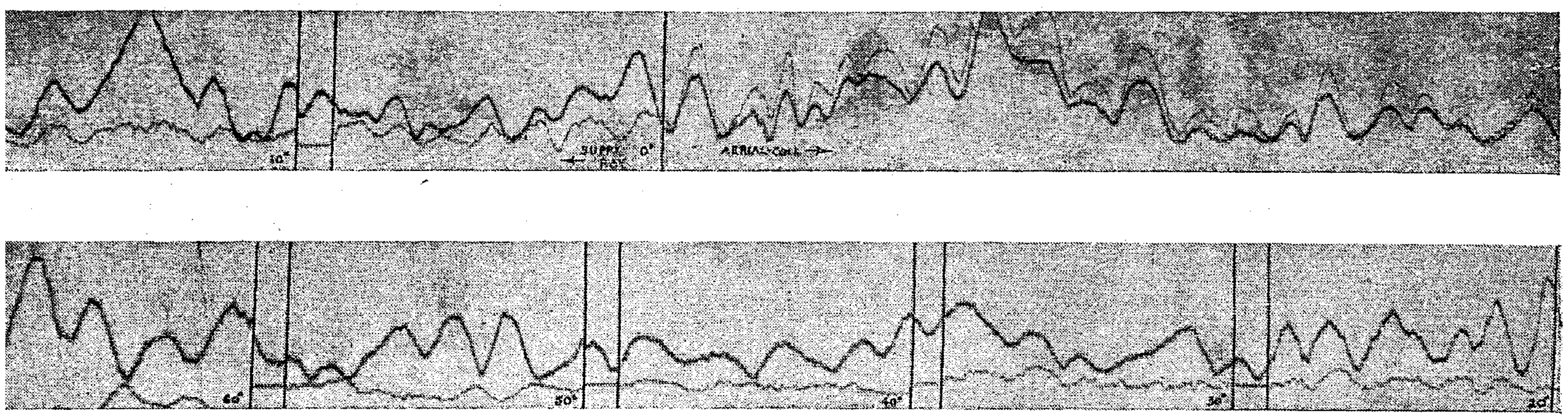


FIG. 14

Of course, owing to the loss of the phase relationship caused by the second rectification, this method is no longer sound in general when more than one ray is present.

It still holds accurately in the following cases:—

(a) When one ray only is present. This is a condition of frequent occurrence.

(b) When two rays are present, one much larger than the other; the suppression of the smaller is still accurate.

This is of great value in allowing the direction of arrival of small disturbing ripples to be determined.

the experimental technique. In the figure the angle given in each section is the ray angle for which total suppression should occur, the denser line giving the aerial e.m.f. and the finer one the suppressed ray e.m.f. While the results are not very definite, it will be noticed that the two e.m.f.'s follow one another very closely in shape until a ray angle of 60° is reached where the first marked departure occurs. At 72° the suppressed ray appears to have reached its minimum, and at 78° we again get the similarity of shape but with one component reversed, showing that over-suppression by the intensity control had taken place. It may therefore be argued that the main ray had a ray angle of 72°, i.e. an angle of incidence of 18°; and that there was a smaller

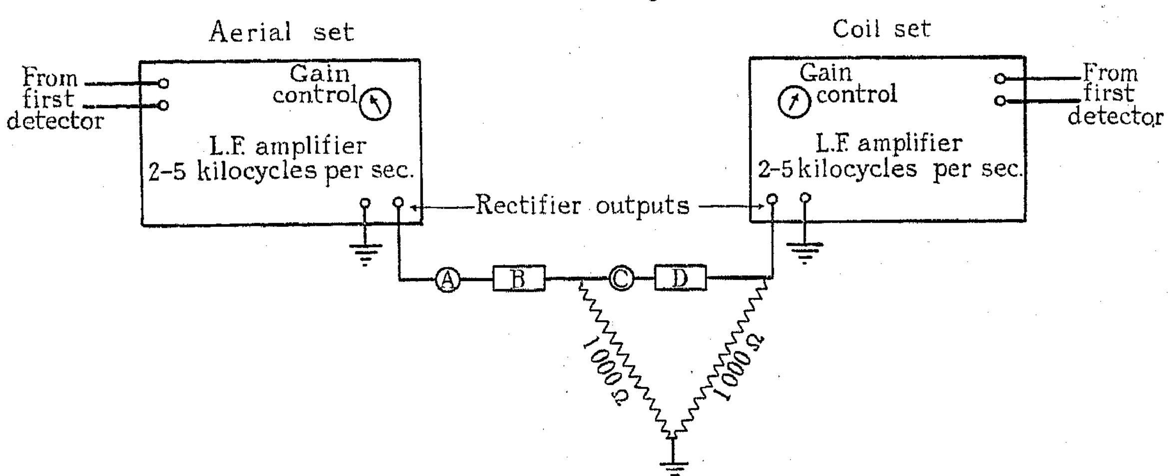
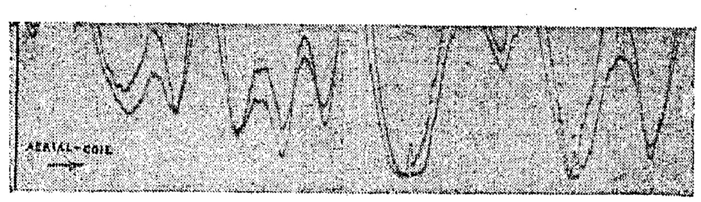


FIG. 15.—Suppressed-ray system.

A = aerial microammeter. C = suppressed-ray microammeter.
B = aerial oscillograph. D = suppressed-ray oscillograph.



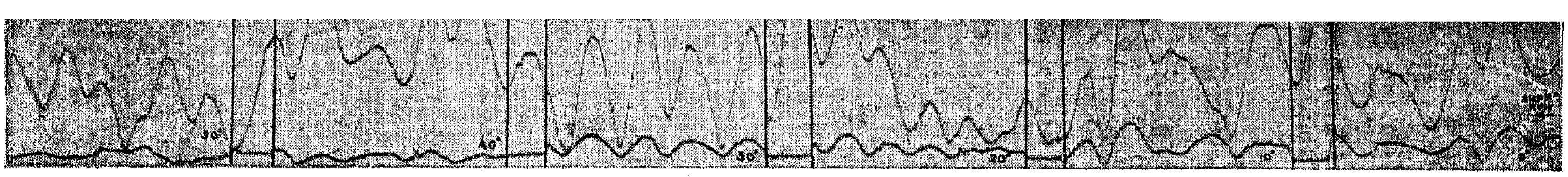


FIG. 16.

In other cases it becomes progressively inaccurate as the rays become more nearly equal and separated by a smaller angle, but even in these cases it may be noted that it still remains strictly correct at phase maxima and minima, i.e. when the two high-frequency components are 0° or 180° apart in phase.

Consequently, even in these cases a great deal of useful information can still be obtained by careful discrimination. It may be pointed out that tests of the second detector show that it is approximately, though not truly, linear.

Unfortunately it was found necessary to use the apparatus for other purposes after only a single day of observation with this system. Only one record was therefore obtained. This is given in Fig. 12. Too much reliance must not be placed on this, since with these observations some practice is required to perfect

one at an angle of incidence of 30° and probably one or two more quite small ones at higher but undetermined angles.

In connection with the abnormally low angle of incidence, reference should be made to page 240, where this effect was observed some two months previously, but a decision was deferred pending further evidence such as is now forthcoming.

Two more recent results of the suppressed ray are given in Figs. 14 and 16. In Fig. 14 the close correspondence in shape and ratio shows that if there is more than one ray present the others are very small. Consequently the apparent angle of suppression gives the true value, i.e. in this case we may say that there is, for all practical purposes at any rate, one ray at an angle of incidence of between 50° and 60°, probably nearer to the former than to the latter.

In Fig. 16, however, the aerial coil ratio is far less constant, and since the cyclic form of the fades strongly suggests a phase origin we can assume that there are two rays present.

The main one appears, as before, to have an angle of incidence between 50° and 60°. The second ray is probably at about 20° on the diagram (i.e. angle of incidence 70°), since the suppressed-ray trace here is small in proportion to the main ray and follows it less accurately.

GENERAL SUMMARY.

Part 1.—From the evidence produced it appears that in general the magneto-ionic theory seems to provide a reasonable explanation of the majority of the observed phenomena. In the more complicated cases, especially when dealing with long distance transmissions, the proof is less rigorous. This is, however, probably due to the limitations of visual analysis of transient phenomena rather than to any breakdown in the theory, and it is probable that the photographic trace method, although it only gives two of the three quantities provided by the cathode-ray tube, may actually be of greater value owing to the permanence of the records.

Part 2.—The most striking fact arising from these results is that it appears definitely possible to have a signal from a station at a distance of 2 500 km consisting of a single ray at an angle of incidence of 30°. Two or more other rays may be present, separated from this by appreciable angles. The persistence of this high-angle ray over considerable periods suggests that there are a certain finite number of possible paths for the ray which have a considerable degree of permanence, and that the apparent variations of angle of incidence of the incoming signal are primarily due to variations in the energy distribution between these fixed paths. It is extremely difficult to reconcile these results with the idea of multiple reflections, since a 30° ray would roughly correspond to a tenth reflection (assuming a layer height of 250 km), and it would be necessary to provide a mechanism by which all other rays, including those so closely related as the ninth and eleventh reflections, were totally absorbed or caused to vanish by electron limitation. At the same time it is possible that, although the general idea is sound, the extremely low angle of incidence (30°) may be exceptional to this particular case.

It should be emphasized that the results given above should not be regarded as a final and definite proof of any particular theory, more especially in Part 2. They were originally undertaken in a spirit of pure inquiry, to determine what actually did happen rather than to prove or disprove any accepted notions, but some of the results were so surprising that they inevitably challenged accepted ideas. Also, owing to the various limitations mentioned in the paper, the experimental results are not nearly as complete as the author would have liked to make them, and it is hoped to carry them much further in the future. As limitations of time would, however, have led to considerable delay in their publication, it was decided to put them forward at once, but it is hoped that they will at present be regarded primarily as a statement of observed phenomena, the theoretical suggestions accompanying them being for the time purely tentative.

This work was carried out as part of the programme of the Radio Research Board and is communicated by permission of the Department of Scientific and Industrial Research.

The author's thanks are due to his colleagues on the staff of the Radio Research Station, Slough, for many suggestions in the course of the work, and also to his assistant, Mr. B. W. S. Challans, for his active assistance in the earlier stages. Special mention should be made of the Superintendent of the Station, Mr. R. A. Watson Watt, who was the originator of the cathode-ray direction-finder and who also first suggested its application to this particular investigation.

ADDENDUM TO PAPER.

(*Received* 10*th February*, 1933.)

About 10 days before the reading of this paper some results were obtained which have a very important bearing on the ideas that have been put forward. They were mentioned at the actual reading and it is thought that they ought to be summarized for the *Journal*.

During the middle of November, daily observations were being made on the downcoming angle from Moscow. The unusual point noticed at once was that on many occasions a large angle of incidence was obtained. The normal value of 30° tended to be 35°, and on several occasions angles of 45° and even 60° were noticed. In particular on the 24th November it was found that three rays were present but that the angle of the steepest was not less than 60°. On that day it happened that a measurement of E-layer density had been made at Slough giving the unusually low mid-day value of $1 \cdot 05 \times 10^5$.

Further comparison on these lines showed that large angles of incidence tended to be accompanied by low E-layer densities, though the comparison was not rigid since the density measurement was made at noon, whereas Moscow does not start up until some hours later. The results, however, distinctly suggested a connection between the angle of incidence and the density of the E layer, whereas no such connection was to be seen with F-layer densities.

This has suggested the following idea. Taking the usual angle of incidence of 30° and the normal layer density of 2×10^5, it will be seen from Fig. 4 that this density is just sufficient to bend the ray horizontal after passing through the E layer. Assuming for the moment that the ionization remains constant between the two layers, the ray would proceed in a straight line striking the F layer at nearly grazing incidence. In this way a long span would be obtained even with a low angle of incidence. This result appears to be so important that its implications require some discussion.

(1) It fits in with the effect referred to above, in that with a lower E-layer density the angle of incidence would tend to increase owing to the decreased refracting power of the layer. Actually this appears to be the crucial test of the method, since under the ordinary theory a decrease in the average density of the layer would result in the ray having to go higher to find enough electrons for refraction. Now on 6 megacycles

at large angles of incidence on the E layer the question of electron limitation would not arise, so that we should expect that periods of lower ionization would give rise to smaller angles of incidence, whereas the reverse appears to be actually the case.

(2) The assumption is made that the density between the apparent heights of the top of the E layer and the bottom of the F layer remains roughly constant. In this connection it must be noted that to obtain the sudden jump often referred to by Appleton and Naismith it is not necessary for the ionization between the layers to fall to zero; a very slight decrease is sufficient to cause it. Moreover, Mr. Naismith has pointed out to the author that in cases where the height is measured for a band of frequencies, the transition from the E to the F layer is not invariably abrupt; but that cases do occur where a series of intermediate points are obtained forming a continuous but steep curve.

It is evident, therefore, that it is possible for the density/height gradient to be positive throughout this space, and, taking this with the fact that the smallest negative gradient is sufficient to cause the abrupt jump, it seems a not unreasonable assumption that the density between the layer remains nearly constant. The direct experimental investigation of this point is one of extreme difficulty owing to the "sheltering" effect of a point of maximum ionization on all that lies above it.

(3) With increasing frequency the refracting power of an E layer of given density decreases, so that it is to be expected that on higher frequencies the angle of incidence at the ground would decrease. Its chief effect would then be to remove the necessity for long spans leaving and arriving at the ground at a grazing angle; they would be lifted a few degrees from it. It is interesting to compare this with the letter from Mr. Walmsley to *Nature*, dated 26th November, 1932, in which he points out that the angle of incidence of transatlantic working on 14 megacycles per sec., though large, is not large enough to fit in with the angle given geometrically by the minimum number of spans.

Under these conditions, of course, the actual angle of incidence will be determined not only by the momentary E-layer density, but also by the form of the (μ, N) curves such as Fig. 4 for the particular transmission involved.

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APPENDIX I.

Study of the Ellipse Produced in a Cathode-Ray Direction-Finder.

When using a cathode-ray direction-finder on crossed coils, the presence of the abnormally polarized ray produces an out-of-phase component which in general gives rise to an ellipse on the tube. The shape and size of this ellipse are, of course, dependent on the relative intensity and phases of the components. In the most general case the number of independent variables is too great to allow the analysis of this ellipse to have any great value, but in certain cases the problem can be sufficiently simplified to give valuable results.

The particular case to be studied is that of short waves from a distant source. In this case the variations are fairly rapid so that it is possible to examine the characteristic behaviour in short periods of observation.

The assumptions on which the analysis is based are:—

(*a*) That no ground ray is present.
(*b*) That the arriving signal consists of two elliptically polarized rays at the same angle of incidence, and of equal ellipticity but opposite directions of rotation.

It will be appreciated that this excludes the possibility of multiple reflections, for which exclusion the primary justification is the reasonableness of the results explained and discussed in the paper.

General Analysis.

Consider two elliptically polarized waves each with ratio of axes K and having their major axes at right angles and opposite senses of rotation. Let the normal to the plane of the ellipses make an angle ϕ with the vertical.

Then the rays are

$$A \cos pt \text{ and } KA \sin pt$$
$$KB \cos (pt + \theta) \text{ and } - B \sin (pt + \theta), \text{ respectively,}$$

if the major axis of A is taken as the axis of x.

The resultant in the plane is given by

$$X = A \cos pt + KB \cos (pt + \theta)$$
$$Y = KA \sin pt - B \sin (pt + \theta)$$

$$\text{Therefore } X = \sqrt{(A^2 + 2AKB \cos \theta + K^2B^2)} \cos (pt + \alpha_1)$$
$$= P \cos (pt + \alpha_1), \text{ say} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{where } \tan \alpha_1 = \frac{KB \sin \theta}{A + KB \cos \theta}$$

$$\text{and } Y = \sqrt{(K^2A^2 - 2ABK \cos \theta + B^2)} \sin (pt - \alpha_2)$$
$$= Q \sin (pt - \alpha_2), \text{ say} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\text{where } \tan \alpha_2 = \frac{B \sin \theta}{KA - B \cos \theta}$$

Changing the origin of time we may write

$$X = P \cos pt$$
$$Y = Q \sin (pt - \alpha)$$

where $\alpha = \alpha_1 + \alpha_2$.

Eliminating pt this gives for the form of the resultant field

$$\frac{X^2}{P^2} + \frac{Y^2}{Q^2} + \frac{2XY}{PQ} \sin \alpha = \cos^2 \alpha \quad . \quad . \quad (3)$$

and the direction of the axes of this ellipse is given by

$$\tan 2\eta = -\frac{2PQ \sin \alpha}{P^2 - Q^2} \quad . \quad . \quad . \quad . \quad (4)$$

and the equation giving the direction of the axes of the ellipse becomes

$$\tan 2\eta = \frac{2PQ \cos \phi \sin \alpha}{P^2 - Q^2 \cos^2 \phi}$$

This reduces to

$$\tan 2\eta = \frac{4AB \sin \theta \cos \phi}{(A^2 + B^2) \sin^2 \phi + 2AB \cos \theta\, (1 + \cos^2 \phi)} \quad . \quad (5)$$

Differentiating with regard to θ we obtain equation (6).

Of this the numerator is the only part not essentially positive, so that as θ increases the ellipse will rotate steadily if

$$(A^2 + B^2) \sin^2 \phi < 2AB(1 + \cos^2 \phi)$$

$$2 \sec^2 2\eta \frac{\partial \eta}{\partial \theta} = \frac{4AB \cos \phi \left\{(A^2 + B^2) \sin^2 \phi \cos \theta + 2AB(1 + \cos^2 \phi)\right\}}{\left\{(A^2 + B^2) \sin^2 \phi + 2AB \cos \theta (1 + \cos^2 \phi)\right\}^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

which reduces to the condition

$$\cos \phi > \frac{A - B}{A + B} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

This equation gives the limiting condition between oscillation and rotation of the ellipse.

This limiting condition has one factor of special interest. Suppose it is nearly, but not quite, satisfied,

i.e. $\cos^2 \phi = \left(\frac{A - B}{A + B}\right)^2 + \kappa$, where κ is small.

Substituting this value in equation (5) we get (8).

This will be infinite (i.e. $2\eta = \frac{1}{2}\pi$) when the denominator is zero.

The condition for this reduces to $\cos \theta = -1 + Z\kappa$, where Z is a finite positive function of A and B, i.e. when $\eta = \frac{1}{4}\pi$, $\theta = \pi - 2Z\kappa$.

Up to this point the equations have been those of general elliptic polarization; but as in this paper we are dealing with circular polarization we shall in future consider this exclusively (i.e. $K = 1$) in order to reduce the algebraical complexity.

Under these conditions therefore we have

$$\tan \alpha_1 = \frac{B \sin \theta}{A + B \cos \theta}\ ; \ \tan \alpha_2 = \frac{B \sin \theta}{A - B \cos \theta}$$

Therefore $\tan \alpha = \dfrac{2AB \sin \theta}{A^2 - B^2}$

that is, $\quad \cos \alpha = \dfrac{A^2 - B^2}{(A^4 + B^4 - 2A^2B^2 \cos 2\theta)^{\frac{1}{2}}}$

$$\sin \alpha = \frac{2AB \sin \theta}{(A^4 + B^4 - 2A^2B^2 \cos 2\theta)^{\frac{1}{2}}}$$

$$\tan 2\eta = -\frac{4AB \sin \theta \dfrac{A - B}{A + B}\left\{1 + \frac{1}{2}\kappa\left(\dfrac{A + B}{A - B}\right)\right\}}{(A^2 + B^2)\left\{1 - \left(\dfrac{A - B}{A + B}\right)^2 - \kappa\right\} + 2AB \cos \theta \left\{1 + \left(\dfrac{A - B}{A + B}\right)^2 + \kappa\right\}} \quad . \quad . \quad . \quad . \quad (8)$$

Consider now the case $A = B$.

Here $\qquad \cos \alpha = 0;\ \sin \alpha = 1$

and the ellipse becomes a straight line inclined at an angle, arc $\tan Q/P$, i.e. two equal circularly polarized fields with opposite directions of rotation form a linear field whose direction depends on the phase angle between them.

We now have to consider the effect of the elliptic field mentioned above on the receiving coils. Since the polarization of the component waves is circular we are no longer compelled to choose the axes in the way defined by the magneto-ionic theory and can choose them in the most convenient directions, namely the intersection of the wave-front with the vertical plane of propagation and at right angles to this. If the coils are in the "maximum" and "minimum" directions we have for the e.m.f.'s in the coils

$$x = X;\ y = Y \cos \phi$$

But when $\theta = \pi$ we have, from equation (8), $\eta = \frac{1}{2}\pi$. Hence, collecting these results, we have

$$\left.\begin{aligned} \theta = 0;\ \ \eta &= 0 \\ \theta = \pi - 2Z\kappa;\ \ \eta &= \tfrac{1}{4}\pi \\ \theta = \pi;\ \ \eta &= \tfrac{1}{2}\pi \end{aligned}\right\}$$

That is to say, when θ steadily increases from 0 to π η increases from 0 to $\frac{1}{4}\pi$ in the range of θ from 0 to $\pi - 2Z\kappa$, and from $\frac{1}{4}\pi$ to $\frac{1}{2}\pi$ in the remaining small range $2Z\kappa$.

That is, the direction of the axes changes slowly from 0 to $\frac{1}{4}\pi$, and then almost discontinuously from $\frac{1}{4}\pi$ to $\frac{1}{2}\pi$.

Hence we can explain the characteristic (6) on page 231 as being due to the fact that we are very close to the limiting condition between rotation and oscillation of the ellipse.

Again, returning to equation (5), suppose B and θ to remain constant and A to vary.

Then

$$2 \sec^2 2\eta \frac{\partial \eta}{\partial A} = \frac{4B \sin \theta \cos \phi \sin^2 \phi (B^2 - A^2)}{\left\{(A^2 + B^2) \sin^2 \phi + 2AB(1 + \cos^2 \phi)\right\}^2}$$

Now if B is nearly equal to A, $B^2 - A^2$ is small. Therefore if the two components of the arriving ray are nearly equal a change in one of them affects the size of the ellipse more than its direction. This is a result of some value.

(B). *Magnitude of Axes.*—If X and Y are the semi-axes of the ellipse from equation (3)

$$\left\{\begin{aligned} \frac{1}{X^2} + \frac{1}{Y^2} &= \frac{1}{P^2 \cos^2 \alpha} + \frac{1}{Q^2 \cos^2 \alpha} \\ \frac{1}{X^2 Y^2} &= \frac{1}{P^2 Q^2 \cos^2 \alpha} \end{aligned}\right.$$

These reduce to

$$\left.\begin{aligned} XY &= \cos \phi \, (A^2 - B^2) \\ X^2 + Y^2 &= P^2 + Q^2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The chief interest in this is that the product of the axes is independent of the phase relation between the components.

Many other relations can be obtained which have not much practical value, but the existing ones may be summarized as follows:—

(1) If the two components are equal the ellipse becomes a straight line for all phase relations.

(2) If $\cos \phi < \dfrac{A - B}{A + B}$ the ellipse will oscillate, otherwise it will rotate, for a steady change in θ.

(3) If A and B are nearly equal a small change in one of them has little effect on the direction.

(4) The product of the axes of the ellipse is independent of the phase between the components.

APPENDIX II.

Form of Trace Obtained when More than One Downcoming Ray is Present.

Suppose we have two downcoming waves at angles of incidence θ_1 and θ_2 and with any phase difference ϕ between them.

Then

Instantaneous e.m.f. in coil

$$= E_1 \cos pt + E_2 \cos (pt + \phi)$$

and instantaneous e.m.f. in aerial

$$= E_1 \sin \theta_1 \cos pt + E_2 \sin \theta_2 \cos (pt + \phi)$$

The R.M.S. values of these are respectively

$$(E_1^2 + E_2^2 + 2E_1E_2 \cos \phi)^{\frac{1}{2}}$$

and $(E_1^2 \sin^2 \theta_1 + E_2^2 \sin^2 \theta_2 + 2E_1E_2 \sin \theta_1 \sin \theta_2 \cos \phi)^{\frac{1}{2}}$

The ratio of these is no longer a constant and varies from

$$\frac{E_1 + E_2}{E_1 \sin \theta_1 + E_2 \sin \theta_2} \quad \text{to} \quad \frac{E_1 - E_2}{E_1 \sin \theta_1 - E_2 \sin \theta_2}$$

but the most important factor to note is that both maxima and minima occur simultaneously on the coil and the aerial, namely when $\cos \phi = \pm 1$, and that this is independent of the momentary values of E_1 and E_2 and therefore independent of intensity fading.* But if a third wave $E_3 \cos (pt + \phi_1)$ at an angle θ_3 is present this result no longer holds in general, since ϕ and ϕ_1 are independent variables which may not pass through 0 and π simultaneously.

Hence we have the following very important result:—

One downcoming wave:—The coil and aerial intensities move together and maintain a constant ratio.

Two downcoming waves:—The coil and aerials still move exactly together but their ratio varies.

Three or more downcoming waves:—The two intensities no longer move together and their maxima and minima occur at different times.

Again, in the case of two rays only, a further important relation can be deduced.

We have seen above that

$$\frac{\text{Aerial intensity}}{\text{Coil intensity}} \text{ at maximum}$$

$$= \frac{E_1 \sin \theta_1 + E_2 \sin \theta_2}{E_1 + E_2} = R \text{ (say)}$$

and

$$\frac{\text{Aerial intensity}}{\text{Coil intensity}} \text{ at minimum}$$

$$= \frac{E_1 \sin \theta_1 - E_2 \sin \theta_2}{E_1 - E_2} = r \text{ (say)}$$

Assume $E_1 > E_2$.
Then if $R > r$

$$\frac{E_1 \sin \theta_1 + E_2 \sin \theta_2}{E_1 + E_2} > \frac{E_1 \sin \theta_1 - E_2 \sin \theta_2}{E_1 - E_2}$$

from which we get

$$\sin \theta_2 > \sin \theta_1$$

Therefore $\qquad \theta_2 > \theta_1$

That is to say, if the coil/aerial ratio at maximum is greater than at minimum, the larger of the two rays has the smaller angle of incidence, and vice versa.

Note.—The assumption underlying this is that intensity fading is slow compared with phase fading.

* The only possible exception to this is if either $(E_1 - E_2)$ or $(E_1 \sin \theta_1 - E_2 \sin \theta_2)$ changes sign at the instant of the phase minimum, but these cases are usually indicated by the fades being total and not partial.

Discussion before the Wireless Section, 7th December, 1932.

Dr. R. L. Smith-Rose: I am particularly interested in the subject of the paper because several years ago Mr. Barfield and I* attempted to obtain some measurements of the resultant magnetic and electric forces of a wave arriving at a receiving station, by measuring certain quantities concerned with the magnitude and direction of those forces. In those days we had to work with much simpler apparatus, which was more complicated to operate than that used by the author. We used one set of apparatus to measure the direction of the magnetic field, and two more sets to measure the direction and intensity of the electric field respectively. These three sets had to be operated by different observers, and it was with some difficulty that we were able to synchronize the observations so that the measurements of all the quantities were carried out at the same time. As we were working on rather longer wavelengths than those dealt with in the paper, the phenomena did not vary quite so rapidly, and we were able to get some useful results from our measurements. The author has had the advantage of that useful tool in radio research, the cathode-ray oscillograph, which enables one to see on a screen what is happening in space to the electric field which comprises the arriving wave. One of the most interesting results that has emerged from the paper is the unexpectedly small angle of incidence of the waves received from Moscow. The author gives an interesting explanation of the way in which this could occur without unduly disturbing our present conceptions of the manner in which the reflecting layers operate.

Prof. L. S. Palmer: The author's great difficulty is to explain the small eccentricity of some of his ellipses without having to assume that the angle of incidence of the downcoming ray is smaller than the simple reflection theory would lead one to expect. Therefore, before accepting the conclusion to which he is forced, I should like to ascertain whether two other possible explanations have been effectively disposed of. (1) To what extent can the reflected ray from the ground produce the observed ellipses? If the coils are influenced by such a reflected ray as well as by a direct downcoming ray, then the observed effects can be produced without invoking the refractive properties of the ionosphere. It is not safe to assume, as is done in the paper, that a downcoming circularly-polarized ray is distorted after reflection from the imperfectly conducting ground, and alone affects the receiving aerial. In the course of some recent experiments at Hull it was found that this reflected ray was not only instrumental in producing elliptically polarized fields but could be artificially varied by thoroughly soaking the ground under the aerial with water. I think, therefore, that such considerations as these might materially affect the eccentricity of the ellipse observed in the present experiments. (2) The second factor which may affect the present results is the nature of the changing polarization of the incident ray when in the Heaviside layer. It is assumed in the paper that the incident ray from the transmitter is polarized perpendicularly to the plane of incidence. By the time the incident ray has emerged from the ionosphere, however, its plane of polarization will have been changed. Any rotation of the plane of polarization will, for a given angle of incidence, tend to reduce the phase difference between the components of the emergent rays and so tend to broaden the ellipse. Thus, depending on the extent of the rotation, the calculated angle of incidence to produce a given phase difference may be considerably larger than the author's calculations would lead one to expect. This second question should, I think, be settled before we accept the conclusion that a very small angle of incidence is the only solution which will account for the small eccentricity of some of the author's ellipses. In conclusion, I think the ultimate interpretation of these important experiments will appreciably add to our knowledge of the mode of propagation of wireless waves in general, and will still further confirm the magneto-ionic theory of propagation in the ionosphere in particular.

Mr. J. A. Ratcliffe: The author's measurements give us good reason for believing that short waves from a distant transmitter are incident at the receiver more steeply than has usually been supposed. It is interesting to speculate on the reason for this; we must not, I think, exclude the possibility of an asymmetrical ray leaving the transmitter at a very large angle with the vertical (i.e. nearly horizontally) but incident steeply at the receiver after only one deviation in the ionosphere. It may be that the experiments of Walmsley,* who finds that for these short waves the rays leave the transmitter at an angle of 10° to the horizontal, support this idea of an asymmetrical ray. For the convenience of those who may wish to test theories of wave propagation by applying the present author's results, I suggest that he should add to his paper a map giving the location of the various transmitters used. I cannot agree with the fundamental reasoning put forward by the author in connection with the last method described for "ray suppression," in which the signal is received independently on a loop and on a vertical aerial, and, after rectification, the two unidirectional currents are sent in opposite directions through a galvanometer. To make the point clear, let us suppose that a signal of amplitude E_1 is arriving at an angle θ_1 with the vertical; then the e.m.f. across the rectifier connected to the aerial will be proportional to $E_1 \sin \theta_1$, while that produced across the loop rectifier will be proportional to E_1. If we suppose that both rectifiers obey a square law, the unidirectional components of the currents from the rectifiers are given by $\alpha(E_1^2/2) \sin^2 \theta_1$ and $\beta(E_1^2/2)$ respectively, where α and β are circuit constants. If these rectified currents are fed together through a d.c. instrument, and if we arrange the circuits, so that

$$\alpha \sin^2 \theta_1 = -\beta$$

then there is no resultant current whatever the value of E_1, i.e. we have suppressed the ray arriving at an angle θ_1 with the vertical. Although I am so far in

* R. L. Smith-Rose and R. H. Barfield: *Proceedings of the Royal Society*, A, 1926, vol. 110, p. 580.

* *Nature*, 1932, vol. 130, p. 814.

complete agreement with the author, I do not agree that the same circuit conditions will necessarily lead to suppression of the ray (E_1, θ_1) in the presence of a second ray (E_2, θ_2) making a different angle with the vertical. Thus if ϕ is the phase difference between E_1 and E_2, the unidirectional components of the currents from the rectifiers are

$$\alpha(\tfrac{1}{2}E_1^2 \sin^2 \theta_1 + \tfrac{1}{2}E_2^2 \sin^2 \theta_2 + E_1E_2 \sin \theta_1 \sin \theta_2 \cos \phi)$$

and $$\beta(\tfrac{1}{2}E_1^2 + \tfrac{1}{2}E_2^2 + E_1E_2 \cos \phi)$$

and if the circuits are adjusted so as to suppress (E_1, θ_1) when this ray exists alone, so that

$$\alpha \sin^2 \theta_1 = -\beta;$$

then in the presence of the second wave (E_2, θ_2) the resultant galvanometer current will be

$$\beta\left[\tfrac{1}{2}E_2^2\left(1 - \frac{\sin^2 \theta_2}{\sin^2 \theta_1}\right) + E_1E_2\left(1 - \frac{\sin \theta_2}{\sin \theta_1}\right) \cos \phi\right]$$

If now the wave E_2 remains constant but the amplitude E_1, or the phase ϕ, of the first wave varies, then the resultant current will vary, i.e. we have not suppressed the effect of the wave (E_1, θ_1). This argument is in no way altered if a "straight line" rectifier is used, as may easily be seen by considering the intensity of the signal obtained by vectorial addition of the two incident waves. In fact, all rectifiers, including the straight-line rectifier, act in virtue of a non-linear relation between the input e.m.f. and the output current, and this inevitably involves "cross-product" terms of the kind indicated for the square-law detector. In the calculations of Appendix I the author assumes that the two waves incident on the receiver have polarizations which are characterized by two similar ellipses having axes in, and at right angles to, the vertical plane, and that the two ellipses are similarly situated, i.e. both have their major axes in the same direction. It seems to me that these assumptions are not in accord with the magneto-ionic theory, which tells us that the ellipses characterizing the polarizations of the two waves have axes in, and at right angles to, the plane containing the incident wave normal and the earth's magnetic field, and further that their major axes are mutually perpendicular, as represented in Fig. A. The author's assumptions therefore seem to be incorrect both with respect to the position of the axes of the ellipses and with respect to their mutual orientation. It would be interesting to find out whether his observations could still be explained by assuming the states of polarization which I have here outlined. In Appendix II he deals with two waves incident simultaneously at different angles and received on a loop aerial and a vertical aerial. He claims to have shown that if only two waves are present the signal maxima must occur simultaneously on both receivers, and that the same is also true for the signal minima. It seems to me that this argument is unsound, because only phase variations are considered. If it is supposed that variations in the relative amplitude (E_1/E_2) may take place without the phase changing appreciably, it is easy to show that the signal variations need not be "in step" on the two receivers. The footnote on page 248 does not deal with the point here at issue. It is concerned with the possibility of signal variations, due chiefly to phase-changes, being interfered with by amplitude changes occurring as a subsidiary effect. The variations which I envisage here are due primarily to amplitude changes, the phase remaining constant or only varying a small amount. Experience with "pulse" transmissions leads us to suppose that rapid variations of amplitude do actually take place, so that effects of this kind must occur, and I therefore do not consider that records like Fig. 10 necessarily indicate the presence of more than two rays. In the past, some confusion has arisen from the fact that when describing the polarization of a wave some authors imagine it to be viewed along the direction of travel, while others imagine it to be viewed in the opposite direction. I should be glad if the author would confirm that the direction of viewing adopted in the paper is that used in Prof. Appleton's original work* on this subject, i.e. along the direction of propagation.

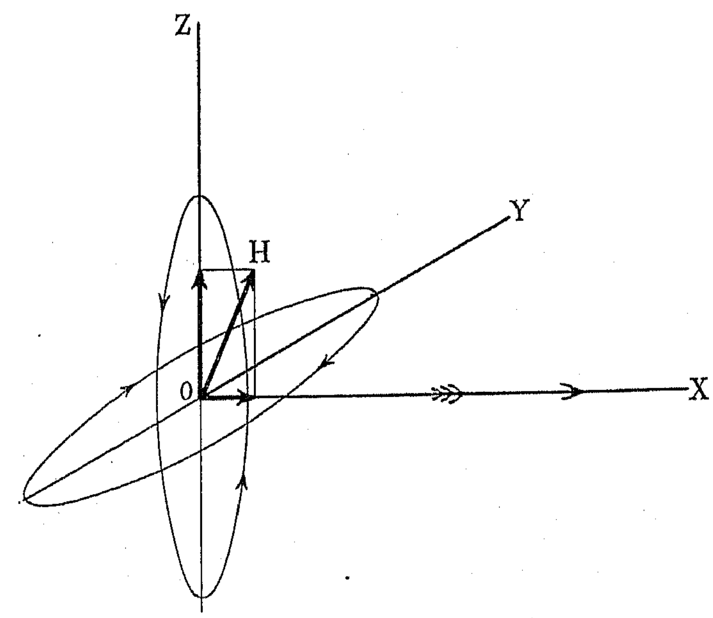


FIG. A.

OH represents earth's magnetic field in plane XOZ.
Plane ZOY is wave-front.
OX is direction of travel of wave.

Dr. E. H. Rayner: I should like to ask whether it would be possible to obtain further useful information by changing the frequency of the distant transmitting station. Would the angle at which one obtains grazing incidence at the lower layer be changed appreciably by small changes in the emitted frequency?

Mr. S. B. Smith: An experiment recently carried out by Mr. T. L. Eckersley† helps one to understand the mechanism responsible for the splitting of a single pulse during transmission through a magneto-ionic medium. A pulse entering such a medium can be resolved into two oppositely polarized components; the velocities of the two components through the medium need not be the same, and consequently a pair or even four pulses may be recorded upon arrival at the receiver. By adopting suitable phasing arrangements in a radiogoniometer Mr. Eckersley was able to eliminate either pulse. The persistence of certain ray angles (sometimes angles of incidence of 30°) has been noted in many

* *Proceedings of the Royal Society*, A, 1928, vol. 117, p. 576.
† *Nature*, 1932, vol. 130, p. 398.

transatlantic facsimile records, and in this connection one is often amazed at the apparent stability of the medium from the echo point of view although fading may be excessive. I should like to ask whether the author has made a detailed study of scattered signals. Some of the results obtained on such signals might be difficult to analyse by the methods described in the paper.

Prof. J. Hollingworth (*in reply*): In reply to Dr. Smith-Rose I should like to put on record that it was his work which first directed my attention to the problem of polarization.

In reply to Prof. Palmer, both the incident and reflected rays are taken into account. In the formula on the middle of page 235 the term $1 + \rho_v$ occurs, and in this the 1 is the coefficient of the incident ray and ρ_v that of the reflected ray. The object of these calculations and of the table at the top of page 236 was to show that while the effect of the earth's conductivity on the reflected wave was to broaden the ellipse formed by the combination of the direct and reflected waves, this effect was not sufficient to account for the degree of broadening actually observed without assuming figures for κ and σ enormously different from those usually accepted. Moreover, while this effect can certainly produce an ellipse on the tube it would be difficult to make it responsible for the regular and rapid cyclic variations. With regard to the second point, no assumption has been made as to the polarization of the incident ray. The form of polarization for free propagation varies throughout the path, and all that can be said is that the component magneto-ionic waves are circularly polarized after their emergence. It is, of course, the variations inside the layer which cause the phase-changes, and it is always possible to obtain from these small momentary ellipses of any broadness, but assuming both components of the magneto-ionic ray to be circularly polarized the ratio of the maximum deflections on the tube in the two directions (not necessarily simultaneously) cannot exceed a figure determined by the angle of incidence.

In regard to the positions of the ellipses of polarization it is true, as Mr. Ratcliffe observes, that their axes have special directions. On emergence from the ionized layer, however, the component of electric force along the direction of propagation is negligible (Goldstein, *loc. cit.*, p. 273), consequently the plane of both ellipses must lie in the wave-front. I am obliged to him, however, for pointing out that the major axes are at right angles. In the particular case under consideration, where the polarization is circular, this of course does not matter so that the deductions made are still true, and it merely causes a permanent shift of 90° in all the relative phases. As, however, it causes the generalization originally given in Appendix I, while still remaining sound in itself, to be inapplicable to magneto-ionic propagation, I have modified it to deal exclusively with circular polarization.

Appendix II definitely deals with phase-fades, the justification for this being that all the experiments tend to show that the rapid periodic variations such as it is applied to are phase-fades, and that intensity fades are much slower and more irregular. Figs. 8(*b*) and 8(*c*) show very clearly the distinction between these two types.

It should be noted that in work of this nature a considerable amount of discretion has to be used in the interpretation of results. The direction of rotation when applied to polarization is taken in the same direction as Prof. Appleton takes it, i.e. when looking in the direction of travel.

Mr. Ratcliffe's comments on the accuracy of the ray-suppression system are sound, and in the paper I have made certain modifications. From an experimental point of view I should, however, like to emphasize the fact, referred to on page 241, that a theoretically sound method of obtaining a "sweep" of angle of suppression is impracticable instrumentally. Consequently one is faced with the alternatives of either abandoning the attempt altogether, or using a system which, while not rigidly accurate, can give results of some value if used with discretion.

Very little work has yet, as far as I know, been done on the analysis of the angles of incidence of down-coming rays, so that even approximate results may be of considerable value.

In regard to Dr. Rayner's inquiry, the wavelength-change method comes more into Prof. Appleton's province than mine. At long distances, however, there is always the question as to whether the path difference is sufficient for its use owing to the large angle of incidence on the layer, though this could only be settled by experiment. On the practical side there is some difficulty in organizing experiments of this type from a transmitter a long way off.

In reply to Mr. Smith, I have not yet made any study of scattered signals, though such a thing would be of great interest. I have rather for the present tried to avoid them in order to reduce the problem under immediate consideration to the simplest possible terms.

CONTACT PHENOMENA IN DIELECTRICS.*

[FURTHER REPORT (REF. L/T45) OF WORK DONE FOR THE ELECTRICAL RESEARCH ASSOCIATION BY THE METROPOLITAN-VICKERS ELECTRICAL CO., LTD.]

(*Paper received* 24*th March*, 1932.)

SUMMARY.

In a previous report † dealing with the significance of contact phenomena in relation to measurements in dielectrics, the E.R.A. foreshadowed further work on a range of dielectrics, with a view to studying the effect of a.c. contact impedance with different types of electrodes.

The present report gives an account of this work and leads to the conclusion that, for accurate determinations of power factor, permittivity, etc., flat metal electrodes should not be used. Both mercury and graphite give satisfactory results; consequently the choice between these two may be settled by considerations of convenience.

The Director of the Electrical Research Association will be pleased to hear from investigators who have occasion to apply any of the proposals outlined herein.

CONTENTS.

(1) INTRODUCTION.

In accordance with the proposals outlined in Ref. L/T31, the following investigation was made of dielectric contact effects, using different electrodes and dielectrics.

The programme included the determination of power factor and permittivity, at 50 cycles per second, with various stresses, on three thicknesses of each of four materials, viz. varnish-paper board, ebonite, porcelain, and glass. Each sample was to be tested with three types of electrodes—flat brass plates, mercury, and aquadag or leiterit.

It was considered that the publication of the results of practical tests should do much to answer certain criticisms, which have been made, of methods of test approved by the E.R.A.

(2) DESCRIPTION OF ELECTRODES.

Two sets of electrodes were designed and constructed. Some slight modifications were suggested by the results of preliminary tests, and the final forms adopted are shown in detail in Figs. 1 and 2.

The flat-plate electrodes (Fig. 1) are clamped between two bakelite sheets A. Independent pressure is obtained on the central electrode C by means of the steel spring S.

The thin sheet of bakelite over the central electrode insulates the electrode from the spring S, and, since it overlaps the brass disc by $\frac{1}{64}$ in., also serves to locate the electrode.

The method of shielding the central electrode is apparent from the figure. Overall dimensions are also given.

It is, of course, desirable that the gap between the central electrode and the guard ring should be as small

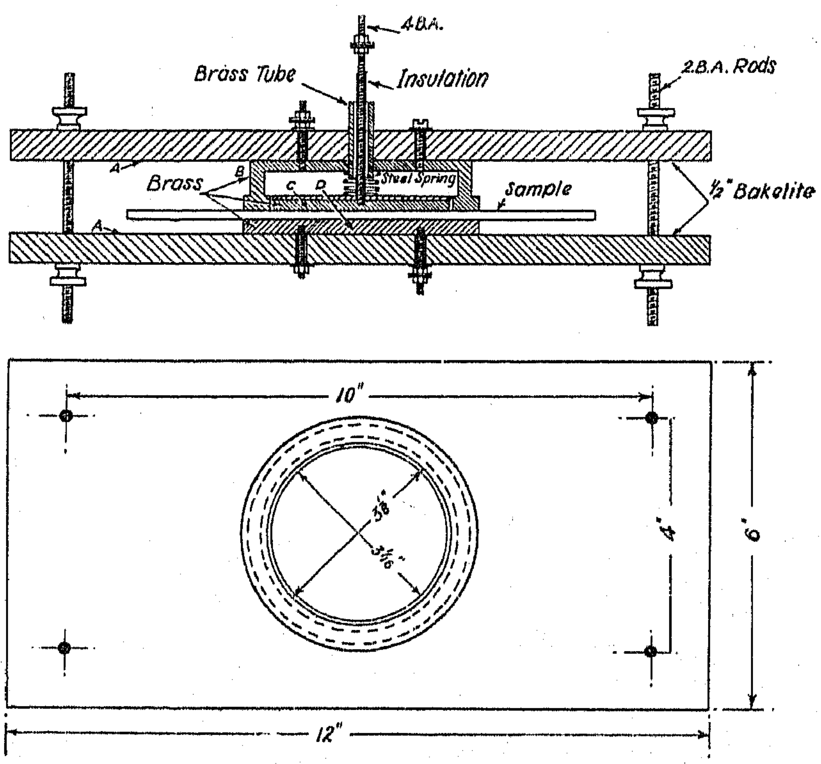


FIG. 1.—Flat plate electrodes.

as possible, and it is essential that the central electrode should be regular in shape in order that measurements of the surface area may be made. Some difficulty was experienced in satisfying these requirements with aquadag electrodes, but eventually the following procedure was adopted. After cleaning the surface of the sample to be tested, a small metal disc, in the centre of which a small conical hole is punched, is affixed by soft wax to the centre of the selected portion of the sample. Using diluted aquadag, and ink compasses, two circles are scribed on the sample, one forming the outer boundary of the central electrode, and the other forming the inner boundary of the guard ring. The compasses are centred in the hole in the metal disc. After some practice and when the correct consistency of aquadag is obtained, it is possible to draw the two circles so that the gap between them is 0·010 in. to 0·015 in. wide.

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications, except those from abroad, should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† Ref. L/T31: "Contact Effects between Electrodes and Dielectrics. An Investigation carried out by B. G. Churcher, C. Dannatt, and J. W. Dalgleish at the Research Laboratories of the Metropolitan-Vickers Electrical Co., Ltd.," *Journal I.E.E.*, 1929, vol. 67, p. 271.

A third circle may be drawn at the same time, if desired, to form the outer boundary of the guard ring. The disc is removed and any trace of wax carefully wiped off.

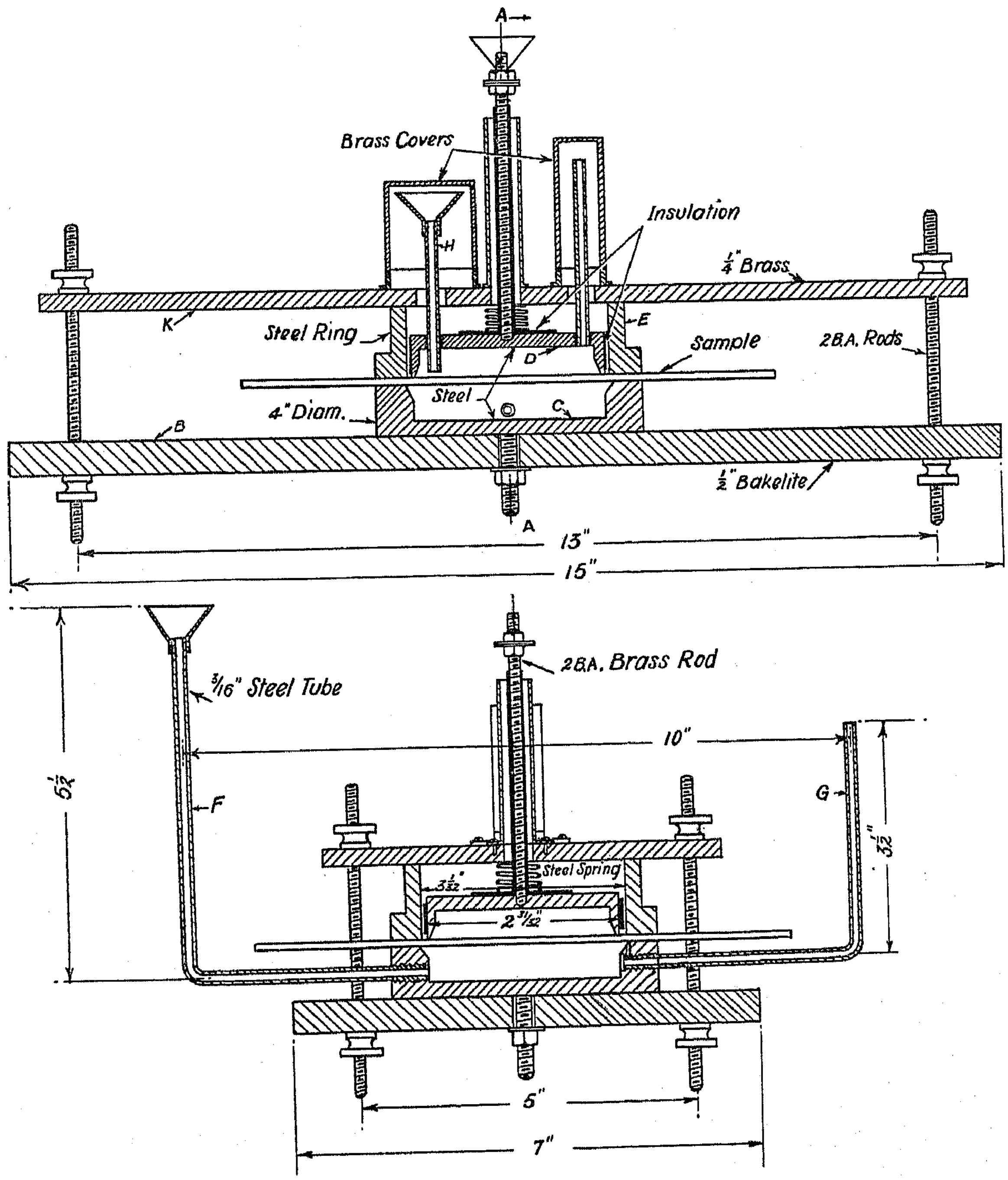
Using a camel-hair brush and a slightly thicker aquadag solution, the central electrode and guard ring are painted on. If the conditions are correct, the aquadag should paint on smoothly without any tendency to form globules. The electrodes are allowed to dry at air temperature and are usually ready for use in about two to three hours.

In these tests the aquadag was backed by flat brass plates, and in order that the clamps shown in Fig. 1 might be utilized, a spare brass disc, $2\frac{1}{2}$ in. diameter, was made, and was used in place of the disc C shown in the illustration.

The mercury electrodes (Fig. 2) are clamped between a brass plate K and a bakelite sheet B. The guard electrode E is a steel ring, the lower surface of which is machined flat. Independent pressure is obtained on the central electrode D by means of the steel spring.

Mercury is poured into D through the steel tube H, the air escaping through the outlet tube J. The brass covers slipped over the tubes H and J complete the shielding of the central electrode.

The wide rim of the high-voltage electrode C is machined flat. The width of the machined surface is $\frac{1}{64}$ in. less than the width of the corresponding surface of the guard electrode E. Inlet and outlet tubes, F and G, are arranged as shown in Fig. 2. The end of the tube G is closed so that the air is forced out through the small hole drilled down from the extreme corner of the electrode. This ensures that no air is trapped. As an additional precaution the apparatus is tilted so that the top of the tube G is level with the top of the tube F while C is being filled.



Section through AA.

FIG. 2.—Mercury electrodes.

(3) METHOD OF TEST.

The tests were carried out at 50 cycles per second, with the sample arranged to form one arm of a bridge network of the Schering type.

The detector was a tuned vibration galvanometer used in conjunction with a valve amplifier, so that ample sensitivity was available with relatively low voltages applied to the bridge.

The resistances, connecting leads, amplifier, etc., were completely shielded. The guard-ring electrodes of the standard air condenser and the sample under test were connected to the shields and earthed.

By means of a Wagner earth device the shielded electrodes of the standard condenser and the sample were brought to earth potential.

In the calculation of permittivity from the value of measured capacitance, the diameter of the sample was measured between points midway in the gap between the central electrode and the guard-ring electrode.

(4) Preliminary Tests.

It was intended to use a mercury guard-ring electrode in place of the flat ring shown in Fig. 2, and in its original form the guard ring was made for this purpose. The high-voltage electrode was made with a thin rim equal in diameter to the outside rim of the guard electrode.

Using this arrangement and the flat-plate electrodes shown in Fig. 1, a series of tests was made on a sample of ebonite $\frac{1}{4}$ in. thick. The results obtained are given in Table 1.

TABLE 1.

Preliminary Tests on Ebonite.

Sample number	Material and size	Electrodes	Stress (volts per mil)	Power factor	Permittivity and percentage change
1	Ebonite, $\frac{1}{4}$ in.	Flat Plate	10	0·0242	4·63
			30	0·0294	4·63+0·98
			55	0·0407	4·63+2·8
			70	0·0443	4·63+3·5
			10	0·0285	4·63+0·98
1	Ebonite, $\frac{1}{4}$ in.	Mercury	10	0·0262	4·67
			30	0·0364	4·67+1·8
			55	0·0448	4·67+3·8
			70	0·0484	4·67+4·5
			10	0·0308	4·67+1·5
1	Ebonite, $\frac{1}{4}$ in.	Aquadag	10	0·0270	4·76
			30	0·0363	4·76+1·4
			55	0·0423	4·76+2·4
			70	0·0451	4·76+3·0
			10	0·0302	4·76+0·61

Attempts to use the mercury electrodes upon a sample of glass $\frac{1}{16}$ in. thick were unsuccessful, as it was impossible to prevent the mercury from leaking from the guard to the central electrode. It was decided, therefore, to use a flat-plate guard ring. A steel ring, $\frac{1}{4}$ in. wide, of suitable diameter, was available and was used in the mercury-electrode tests included in Table 2.

As it was observed that changes of laboratory temperature were producing corresponding changes in permittivity and power factor, it was decided that all further tests should be made with the sample in an enclosure maintained at a constant temperature of 25° C. Further, it was anticipated that difficulty would be experienced with the mercury electrodes when testing thinner specimens, owing to the bending of the material.

TABLE 2.

Preliminary Tests on Glass.

Sample number	Material and size	Electrodes	Stress (volts per mil)	Power factor	Permittivity and percentage change
2	Glass, $\frac{1}{16}$ in.	Flat Plate	5	0·0200	6·54
			20	0·0203	6·54+0·06
			30	0·0206	6·54+0·13
			40	0·0231	6·54+0·45
			5	0·0201	6·54+0·05
2	Glass, $\frac{1}{16}$ in.	Mercury	5	0·0234	7·75
			20	0·0234	7·75
			30	0·0236	7·75+0·02
			40	0·0211	7·75−0·32
			5	0·0236	7·75
2	Glass, $\frac{1}{16}$ in.	Aquadag	5	0·0230	7·65
			20	0·0231	7·65
			30	0·0231	7·65
			40	0·0231	7·65
			5	0·0231	7·65

TABLE 3.

Further Tests on Glass, with Improved Electrode Clamps.

Sample number	Material and size	Electrodes	Stress (volts per mil)	Power factor	Permittivity and percentage change
2	Glass, $\frac{1}{16}$ in.	Flat Plate	5	0·0298	7·10
			10	0·0311	7·10+0·15
			20	0·0323	7·10+0·26
			30	0·0343	7·70+0·51
			5	0·0323	7·10+0·12
2	Glass, $\frac{1}{16}$ in.	Mercury	5	0·0299	7·72
			20	0·0301	7·72+0·07
			30	0·0308	7·72+0·21
			40	0·0344	7·72+1·09
			5	0·0328	7·72+0·88
2	Glass, $\frac{1}{16}$ in.	Aquadag	5	0·0289	7·75
			20	0·0289	7·75
			40	0·0289	7·75
			60	0·0289	7·75
			5	0·0289	7·75

Accordingly, the high-voltage electrode C, shown in Fig. 2, was constructed to improve the clamping arrangement. A series of results obtained with these conditions on the same sample of glass is given in Table 3.

TABLE 4.

Preliminary Tests to Study Effect of Width of Gap between Electrode and Guard Ring.

Sample number	Material and size	Electrodes: High-voltage	Electrodes: Central	Electrodes: Guard	Gap width (inch)	Stress (volts per mil)	Power factor	Permittivity and percentage change
2	Glass, $\frac{1}{16}$ in.	Mercury	Aquadag	Aquadag	0·015	5	0·0258	7·71
						20	0·0258	7·71+0·05
						30	0·0261	7·71+0·08
						60	0·0264	7·71+0·15
						5	0·0264	7·71+0·27
2	Glass, $\frac{1}{16}$ in.	Mercury	Aquadag	Aquadag	0·045	5	0·0272	7·66
						20	0·0272	7·66+0·08
						30	0·0272	7·66+0·08
						60	0·0273	7·66+0·12
						5	0·0273	7·66+0·23
2	Glass, $\frac{1}{16}$ in.	Mercury	Mercury	Aquadag	0·050	5	0·0286	7·58
						20	0·0286	7·58
						30	0·0286	7·58
						60	0·0286	7·58+0·05
						5	0·0286	7·58
2	Glass, $\frac{1}{16}$ in.	Mercury	Mercury	$\frac{1}{2}$ in. steel ring	0·030	5	0·0277	7·82
						20	0·0283	7·82
						30	0·0283	7·82
						60	0·0273	7·82—0·24
						5	0·0283	7·82+0·04

TABLE 5.

Power Factor and Permittivity of Specified Dielectrics under Different Conditions of Test.

Sample number	Material and size	Stress (volts/mil)	Flat-plate electrodes: Power factor	Flat-plate electrodes: Permittivity and percentage change	Mercury electrodes: Power factor	Mercury electrodes: Permittivity and percentage change	Aquadag electrodes: Power factor	Aquadag electrodes: Permittivity and percentage change
3	Ebonite, $\frac{1}{64}$ in.	5	0·0058	2·02	0·0066	3·09	0·0056	3·07
		30	0·0054	2·02	0·0067	3·09+0·10	0·0056	3·07+0·14
		55	0·0055	2·02	0·0069	3·09+0·10	0·0058	3·07+0·16
		80	0·0056	2·02+0·07	0·0071	3·09+0·15	0·0063	3·07+0·25
		100	0·0074	2·02+0·30	0·0071	3·09+0·20	0·0064	3·07+0·28
		5	0·0054	2·02	0·0066	3·09+0·10	0·0058	3·07+0·14
4	Ebonite, $\frac{1}{64}$ in.	5	0·0042	2·09	0·0066	2·89	0·0066	2·89
		30	0·0044	2·09+0·04	0·0066	2·89	0·0067	2·89
		50	0·0044	2·09+0·07	0·0066	2·89	0·0067	2·89+0·04
		80	0·0045	2·09+0·18	0·0066	2·89+0·02	0·0069	2·89+0·05
		100	0·0058	2·09+0·31	0·0066	2·89+0·05	0·0069	2·89+0·06
		5	0·0044	2·09+0·06	0·0066	2·89+0·01	0·0066	2·89+0·04
5	Ebonite, $\frac{1}{64}$ in.	5	0·0078	2·47	0·0182	3·05	0·0071	3·08
		30	0·0083	2·47+0·04	0·0194	3·05+0·19	0·0071	3·08+0·03
		50	0·0086	2·47+0·06	0·0204	3·05+0·34	0·0071	3·08+0·06
		80	0·0094	2·47+0·17	0·0218	3·05+0·51	0·0074	3·08+0·08
		100	0·0099	2·47+0·24	0·0222	3·05+0·67	0·0075	3·08+0·08
		5	0·0083	2·47+0·05	0·0192	3·05+0·22	0·0071	3·08+0·01

TABLE 5—*continued.*

Sample number	Material and size	Stress (volts/mil)	Flat-plate electrodes		Mercury electrodes		Aquadag electrodes	
			Power factor	Permittivity and percentage change	Power factor	Permittivity and percentage change	Power factor	Permittivity and percentage change
6	Ebonite, $\frac{1}{32}$ in.	5	0·0072	2·57	0·0075	2·91	0·0078	3·00
		25	0·0072	2·57+0·02	0·0075	2·91	0·0081	3·00
		60	0·0075	2·57+0·13	0·0075	2·91+0·11	0·0083	3·00+0·04
		75	0·0110	2·57+0·53	0·0068	2·91+0·09	0·0085	3·00+0·04
		90	0·0116	2·57+0·73	0·0072	2·91+0·14	0·0085	3·00+0·05
		5	0·0072	2·57+0·09	0·0075	2·91+0·14	0·0080	3·00
7	Ebonite, $\frac{1}{16}$ in.	5	0·0146	2·79	0·0162	2·98	0·0166	2·98
		15	0·0149	2·79	0·0162	2·98+0·01	0·0167	2·98
		25	0·0151	2·79+0·03	0·0162	2·98+0·02	0·0167	2·98+0·01
		40	0·0151	2·79+0·05	0·0162	2·98+0·03	0·0167	2·98+0·01
		50	0·0151	2·79+0·05	0·0162	2·98+0·03	0·0167	2·98+0·01
		5	0·0149	2·79+0·04	0·0162	2·98+0·02	0·0166	2·98+0·01
8	Varnish-paper board, $\frac{1}{16}$ in.	5	0·0460	4·33	0·0522	5·07	0·0539	5·09
		10	0·0463	4·33+0·07	0·0522	5·07+0·03	0·0539	5·09
		20	0·0463	4·33+0·08	0·0522	5·07+0·05	0·0539	5·09
		40	0·0463	4·33+0·12	0·0528	5·07+0·11	0·0539	5·09
		45	0·0473	4·33+0·20	0·0532	5·07+0·20	0·0541	5·09
		5	0·0462	4·33+0·08	0·0522	5·07+0·03	0·0539	5·09
9	Varnish-paper board, $\frac{1}{16}$ in.	5	0·0550	4·62	0·0620	5·18	0·0642	5·17
		10	0·0552	4·62+0·02	0·0620	5·18	0·0643	5·17+0·03
		20	0·0556	4·62+0·04	0·0618	5·18+0·01	0·0643	5·17+0·03
		40	0·0556	4·62+0·10	0·0618	5·18+0·02	0·0648	5·17+0·07
		45	0·0563	4·62+0·60	0·0618	5·18+0·05	0·0648	5·17+0·07
		5	0·0558	4·62+0·09	0·0618	5·18+0·06	0·0648	5·17+0·08
10	Varnish-paper board, $\frac{1}{8}$ in.	2	0·1018	5·57	0·1052	6·05	0·1085	6·06
		10	0·1020	5·57+0·03	0·1057	6·05+0·09	0·1080	6·06
		20	0·1026	5·57+0·05	0·1057	6·05+0·13	0·1082	6·06
		40	0·1027	5·57+0·12	0·1065	6·05+0·22	0·1085	6·06+0·03
		45	0·1061	5·57+0·50	0·1059	6·05+0·20	0·1095	6·06+0·13
		2	0·1024	5·57+0·08	0·1061	6·05+0·29	0·1087	6·06+0·09
11	Varnish-paper board, $\frac{1}{4}$ in.	1	0·136	5·27	0·144	5·66	0·137	5·57
		5	0·137	5·27+0·14	0·144	5·66+0·06	0·137	5·57+0·12
		25	0·141	5·27+0·69	0·145	5·66+0·14	0·139	5·57+0·35
		35	0·147	5·27+1·42	0·146	5·66+0·23	0·140	5·57+0·47
		45	0·151	5·27+1·95	0·146	5·66+0·29	0·141	5·57+0·61
		1	0·142	5·27+0·92	0·146	5·66+0·24	0·139	5·57+0·51
12	Porcelain*, $\frac{1}{4}$ in.	1	0·150	25·2	0·350	92·6	0·381	98·0
		5	0·192	26·5	0·350	92·6 +0·12	0·380	98·0 +0·15
		10	0·454	29·9	0·350	92·6 +0·27	0·376	98·0 +0·33
		20	—	—	0·341	92·6 +1·75	0·373	98·0 +1·02
		1	0·150	25·7	0·341	92·6 +0·89	0·374	98·0 +0·41
13	Glass, $\frac{1}{16}$ in.	5	0·0222	6·11	0·0277	7·82	0·0289	7·75
		20	0·0229	6·11	0·0283	7·82	0·0289	7·75
		30	0·0229	6·11	0·0283	7·82	0·0289	7·75
		45	0·0512	6·11+2·23	0·0280	7·82−0·10	0·0289	7·75
		5	0·0222	6·11+0·05	0·0283	7·82+0·04	0·0289	7·75

* Not electrical porcelain.

TABLE 5—*continued.*

Sample number	Material and size	Stress (volts/mil)	Flat-plate electrodes		Mercury electrodes		Aquadag electrodes	
			Power factor	Permittivity and percentage change	Power factor	Permittivity and percentage change	Power factor	Permittivity and percentage change
14	Glass, $\frac{1}{8}$ in.	2	0·0226	6·22	0·0250	6·90	0·0266	6·89
		10	0·0228	6·22+0·06	0·0252	6·90+0·03	0·0266	6·89
		20	0·0228	6·22+0·13	0·0252	6·90+0·03	0·0268	6·89
		40	0·0275	6·22+0·67	0·0229	6·90−0·21	0·0268	6·89
		45	0·0334	6·22+1·20	0·0233	6·90−0·12	0·0268	6·89
		2	0·0232	6·22+0·14	0·0252	6·90+0·09	0·0268	6·89
15	Glass, $\frac{1}{4}$ in.	1	0·0294	6·80	0·0302	7·09	0·0311	7·01
		5	0·0296	6·80	0·0302	7·09+0·06	0·0311	7·01
		25	0·0298	6·80+0·05	0·0298	7·09−0·01	0·0311	7·01+0·01
		35	0·0336	6·80+0·41	0·0287	7·09−0·19	0·0311	7·01+0·04
		45	0·0347	6·80+0·53	0·0283	7·09−0·27	0·0311	7·01+0·04
		1	0·0306	6·80+0·11	0·0304	7·09+0·09	0·0311	7·01+0·04
16	Varnished cloth, 0·0055 in.	15	0·118	4·36	0·260	10·2	0·213	12·8
		30	0·118	4·36+0·20	0·261	10·2+0·25	0·213	12·8+0·20
		40	0·119	4·36+0·41	0·261	10·2+0·50	0·213	12·8+0·20
		50	0·120	4·36+0·60	0·261	10·2+0·50	0·214	12·8+0·31
		15	0·119	4·36+0·20	0·261	10·2+0·50	0·213	12·8+0·25

TABLE 6.

Results of Tests to Study the Effect of Slightly Dirty Mercury Electrodes.

Sample number	Material and size	Stress (volts/mil)	Mercury electrodes (slightly dirty)		Aquadag electrodes	
			Power factor	Permittivity and percentage change	Power factor	Permittivity and percentage change
17	Varnish-paper board, $\frac{1}{8}$ in. ..	2	0·126	6·08	0·116	5·96
		10	0·126	6·08+0·05	0·117	5·96+0·06
		20	0·126	6·08+0·10	0·117	5·96+0·09
		40	0·126	6·08+0·11	0·118	5·96+0·24
		45	0·125	6·08−0·01	0·118	5·96+0·31
		2	0·126	6·08+0·18	0·118	5·96+0·31
18	Glass, $\frac{1}{8}$ in.	2	0·0240	7·71	0·0255	7·75
		10	0·0240	7·71+0·02	0·0257	7·75
		20	0·0240	7·71+0·02	0·0258	7·75+0·01
		40	0·0226	7·71−0·13	0·0260	7·75+0·01
		45	0·0236	7·71	0·0260	7·75+0·03
		2	0·0236	7·71+0·10	0·0257	7·75+0·01
19	Ebonite, $\frac{1}{16}$ in..	5	0·0149	2·95	0·0151	2·91
		10	0·0149	2·95	0·0151	2·91+0·02
		20	0·0149	2·95	0·0151	2·91+0·02
		40	0·0149	2·95+0·02	0·0151	2·91+0·04
		45	0·0151	2·95+0·02	0·0151	2·91+0·06
		5	0·0149	2·95+0·02	0·0151	2·91+0·02

Two further points required some investigation before proceeding with the main tests; namely, the effect of the width of guard ring used with the mercury electrodes, and the effect of the width of gap between the central and guard electrodes.

The same sample of glass was tested with mercury as the high-voltage electrode and with aquadag for the other electrodes, the gap being 0·015 in. This was repeated with a gap of 0·045 in.

A further test was made, using mercury for the central and high-voltage electrodes with an aquadag guard ring, the gap in this case being approximately 0·050 in. As each of these tests gave satisfactory results, it was presumed that no effect due to gap width or to the edge of the central electrode being of steel was to be expected.

Finally a test was made using the flat-plate guard ring $\frac{1}{2}$ in. wide, as shown in Fig. 2.

The results of these tests are given in Table 4.

(5) Principal Tests.

A complete series of tests at 50 cycles per second and 25° C. was made with each of the three types of electrodes with stresses up to 45 volts per mil, on each of the following samples:—

$\frac{1}{64}$ in. Ebonite	3 samples
$\frac{1}{32}$ in. Ebonite	1 sample
$\frac{1}{16}$ in. Ebonite	1 sample
$\frac{1}{16}$ in. Glass	1 sample
$\frac{1}{8}$ in. Glass	1 sample
$\frac{1}{4}$ in. Glass	1 sample
$\frac{1}{4}$ in. Porcelain	1 sample
0·006 in. Varnished cloth	1 sample
$\frac{1}{16}$ in. Varnish-paper board	2 samples
$\frac{1}{8}$ in. Varnish-paper board	1 sample
$\frac{1}{4}$ in. Varnish-paper board	1 sample

The porcelain sample was of poor quality * but was the only one available in the form of a flat sheet.

In testing the varnished cloth a drying agent was placed in the enclosure to ensure a low relative humidity. It was found necessary to make a further high-voltage electrode for this test, the machined surface being made sufficiently wide to support the central electrode rim. In all other respects the design was similar to that shown in Fig. 2.

Complete results are given in Table 5.

* Not electrical porcelain.

(6) Condition of Mercury.

In the preceding tests care was taken that the mercury should be chemically clean. In order to investigate the effect of using dirty mercury, tests were made on one sample of varnish-paper board, one sample of glass, and one sample of ebonite, comparing aquadag and slightly dirty mercury electrodes.

The results are given in Table 6.

(7) Observations.

An examination of the results given in Table 5 shows that the use of flat-plate electrodes gives permittivity values which are considerably lower than the corresponding values obtained with either mercury or aquadag electrodes. Moreover, the power factors obtained with flat-plate electrodes are low at low stresses but increase rapidly with increasing stress, and in some cases considerably exceed the corresponding values obtained with either of the other types of electrodes. These discrepancies are more pronounced with thin samples.

Good agreement is obtained between the mercury and aquadag electrode results both for permittivity and for power factor, with the exception of the tests on sample No. 5 ($\frac{1}{64}$ in. ebonite).

In one or two cases the use of mercury gives slightly erratic results with increasing stress.

The majority of the samples do not appear to recover completely from the small changes of permittivity and power factor produced by stressing.

Although a higher power factor is obtained for the $\frac{1}{8}$ in. varnish-paper board sample when using slightly dirty mercury as compared with aquadag, no serious differences are observed in the tests on $\frac{1}{8}$ in. glass and $\frac{1}{16}$ in. ebonite.

As a result of this investigation, it is recommended that flat-plate electrodes should not be used for this class of work. They may, of course, be permissible for some shop tests where nothing more than a rough guide is required. The choice between mercury and aquadag may be settled by considerations of convenience.

Provided that the construction of fairly elaborate electrodes is no serious objection, the use of mercury involves less preparation and is to be recommended where a large number of samples have to be tested. Aquadag has the advantage that it may be used for samples which are not flat, and should be used in all cases where the use of mercury is considered to be inconvenient.

MUTUAL INDUCTION BETWEEN POWER AND TELEPHONE LINES UNDER TRANSIENT CONDITIONS.*

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(*Paper received* 9*th April*, 1932.)

SUMMARY.

One of the most important problems in telephone interference at the present time is that of the dangerous voltages induced in communication circuits when an earth fault occurs on an adjacent high-tension transmission line with earthed neutral. Theoretical formulæ have been developed which enable the coupling between the two circuits to be calculated, and measurements in the field have shown that, provided the resistivity of the earth is known, these formulæ will enable an accurate forecast to be made of the induced voltage in the communication line, after steady fault conditions have been established.

The present paper examines the derivation of a mathematical expression for the coupling under the initial transient conditions. In order to see whether the variation between the initial and final values of the coupling is important, a number of practical cases have been worked out numerically for the first time. This has enabled curves to be drawn showing the induced voltage during the first few microseconds of a fault. The result of the investigation is to establish the sufficiency of the simpler steady-state methods of dealing with the problem for practical cases.

(1) INTRODUCTION.

It is a matter of common knowledge that when an earth fault occurs on a power transmission system with earthed neutral-points, high voltages may be induced in neighbouring communication circuits. The induced voltage appears as a potential with respect to earth of points on the communication circuit. It is due to electromagnetic induction from the earth-return current in the short-circuited power line.

The Comité Consultatif International des Communications Téléphoniques à Grande Distance, in the 1930 edition of its Directives for the protection of telephone lines against the influence of high-tension systems, states that danger exists when, during the short time which must elapse before the circuit breakers disconnect the faulty power line, the telephone line is subjected to an induced longitudinal voltage exceeding 300 volts. Similar considerations give rise to the demands made by the British Post Office to the Central Electricity Board for a definite limitation of the possible short-circuit current in those transmission lines of the grid system which have long parallels with telephone or telegraph circuits.

The theoretical distribution of the fault current in the earth has been studied by Pollaczek,† Carson,‡ and others. The first two of these investigators have given formulæ yielding results which are in numerical agreement with one another and with the results of measurements in the field, and enable the induced voltage in the communication line to be calculated. These formulæ have been generally accepted, and curves based on them are given in the C.C.I. Directives, and also in the *I.E.E. Journal* (1931, vol. 69, p. 1120). When making the calculations, transient phenomena are neglected and the short-circuit current assumed is a steady current derived from a consideration of the maximum output of the generators connected to the power network and the impedance of the transformers and lines through which they act.

The transient phenomena which are neglected may be discussed under two headings:—

(i) The "long time" transients occupying several cycles, and during which the induced voltage, like the fault current, has other than its final value.

The magnitude of the fault current during this period is determined by the inertia and reactance of the rotating machinery supplying the line.

(ii) "Short time" transient effects, due to the fact that for a very sudden rise in the earth current the coupling between the power and communication circuits will differ from that calculated for the steady conditions.

The phenomena mentioned under (i) above have been extensively studied by means of oscillographic investigations on actual lines and generators. Any changes which take place in the short-circuit current as the generators, etc., adapt themselves to the new conditions, can generally be estimated. If it is needed, the induced voltage on a communication line during this period can be roughly calculated by the method adopted when steady sinusoidal conditions have been fully established. For changes which are spread over several cycles the coupling between the two lines can be assumed to be practically constant.

The object of the present paper is to examine from a practical standpoint the importance of the induced potentials in the communication line due to the more abrupt changes in the earth current mentioned under (ii). Several writers have discussed the coupling between two earth-return circuits under transient conditions. So far it has not been shown whether the neglect of the variation in this coupling in the usual calculations is justified.

It may also be pointed out, though this is generally overlooked, that with the neutral points of the line-side windings of transformers earthed at both ends of a line,

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications, except those from abroad, should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† See Bibliography, (1). ‡ *Ibid.*, (2).

earth currents may be caused to flow momentarily during switching operations. The effects on a neighbouring communication circuit will then be similar to those occurring during the first few micro-seconds of an earth fault.

(2) Theoretical Statement of the Problem.

Let $Z_{12}(t)$ be the voltage induced in the communication conductor, per *unit* length, due to a *unit* discontinuous earth-return current in the power line, that is a current which at time $t<0$ is zero, becomes unity at time $t=0$, and remains unity thereafter.

Then if the actual short-circuit current is equal to $I(t)$ [1], where the introduction of the function [1] indicates that this current is zero at times less than 0, the transient voltage is given by the transformed Boltzmann-Hopkinson superposition theorem, viz.

$$V(t) = \frac{d}{dt}\int_0^t Z_{12}(t)I(t-\tau)d\tau \quad . \quad . \quad . \quad (1)$$

$V(t)$ is the induced voltage on the communication line at any time, t, after the commencement of the earth current. The problem therefore resolves itself firstly into the determination of the mutual impedance function, $Z_{12}(t)$.

$Z_{12}(t)$ may be formulated as the Fourier integral

$$Z_{12}(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\frac{e^{j\omega t}}{j\omega}Z_{12}(\omega)d\omega \quad . \quad . \quad . \quad (2)$$

where $Z_{12}(\omega)$ is the steady-state mutual impedance between the two circuits for a steady sinusoidal current of frequency f, and ω equals $2\pi f$.

Taking the formula given by Pollaczek for the "generalized coefficient of mutual induction" (M) between two earth-return circuits

$$M = -\frac{4}{k^2x^2} + 4\frac{\text{kei}'(|kx|) - j\,\text{ker}'(|kx|)}{|kx|}. \quad (3)$$

where $k = \left(\exp.\frac{3\pi}{4}j\right)\sqrt{(4\pi\sigma\omega)}$, $\quad |k| = \sqrt{(4\pi\sigma\omega)}$

x = separation between the two circuits, in cm, and
σ = conductivity of the earth in C.G.S. units.

When multipled by $j\omega$, Pollaczek's formula gives the value of the mutual impedance between the two circuits under steady-state conditions, viz. $Z_{12}(\omega)$. Equation (3) holds for all separations when both conductors are on the surface of the earth. When one (or both) of the conductors is suspended on towers and the aerial field has to be taken into account, it is applicable, with the usual values of the earth conductivity, for separations exceeding 150 metres.

The functions kei′ and ker′ are defined as being related to the Bessel function of the second kind for imaginary arguments as follows:—

$$\text{ker}'\,z \pm j\,\text{kei}'\,z = -j^{\pm\frac{1}{2}}K_1(zj^{\pm\frac{1}{2}})^*$$

kei′ ($|kx|$) $- j$ ker′ ($|kx|$) therefore becomes equal to $j\sqrt{(j)}K_1(|kx|\sqrt{j})$, and Pollaczek's expression may be rewritten

$$M = -\frac{4j}{|kx|^2} + \frac{4j\sqrt{(j)}K_1[|kx|\sqrt{(j)}]}{|kx|}$$

or

$$Z_{12}(\omega) = j\omega M$$
$$= \frac{1}{\pi\sigma x^2}\{1 - a\sqrt{(j\omega)}K_1[a\sqrt{(j\omega)}]\}$$

where $a = \sqrt{[4\pi\sigma x^2]}$.

Substituting this value for $Z_{12}(\omega)$ in equation (2), we obtain

$$Z_{12}(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\frac{e^{j\omega t}}{j\omega}\cdot\frac{1}{\pi\sigma x^2}\{1 - a\sqrt{(j\omega)}K_1[a\sqrt{(j\omega)}]\}d\omega$$

Put $j\omega = p = \frac{d}{dt}$ in this equation, then

$$Z_{12}(t) = \frac{1}{2\pi j}\int_{-j\infty}^{+j\infty}\frac{e^{pt}}{p}\cdot\frac{1}{\pi\sigma x^2}\{1 - a\sqrt{(p)}K_1[a\sqrt{(p)}]\}dp \quad . \quad (4)$$

Now

$$\frac{1}{2\pi j}\int_{-j\infty}^{+j\infty}\frac{e^{pt}}{p}\cdot\frac{1}{\pi\sigma x^2}dp = \frac{1}{\pi\sigma x^2}[1] \quad . \quad . \quad . \quad (5a)$$

and

$$-\frac{1}{2\pi j}\int_{-j\infty}^{+j\infty}\frac{e^{pt}}{p}\cdot\frac{1}{\pi\sigma x^2}a\sqrt{(p)}K_1[a\sqrt{(p)}]dp$$
$$= -\frac{1}{\pi\sigma x^2}\cdot a\sqrt{(p)}K_1[a\sqrt{(p)}][1] \quad . \quad (5b)$$

Using the Fourier transformation

$$F(f)p[1] = G(t)$$

where

$$F(f) = \frac{a}{\sqrt{p}}\cdot K_1(a\sqrt{p}) - \frac{1}{p}$$
$$G(t) = e^{-\frac{a^2}{4t}} - 1^*$$

we have $-\frac{1}{\pi\sigma x^2}a\sqrt{(p)}K_1[a\sqrt{(p)}][1] = -\frac{e^{-\pi\sigma x^2/t}}{\pi\sigma x^2}[1]$

So that, from equations (4) and (5),

$$Z_{12}(t) = \frac{1}{\pi\sigma x^2}(1 - e^{-\pi\sigma x^2/t}),\ t \geqslant 0 \quad . \quad . \quad (6)$$

This formula is of considerable importance in the calculations of induction during transient conditions. It has been given by L. C. Peterson† and J. Riordan‡ in America, and is in agreement with Ollendorf's latest work published in Germany.§

Peterson derives the expression for $Z_{12}(t)$ in the manner outlined above, but quotes it as being the limiting case for a more general formula which takes into account

* K_1 represents the Bessel function of the second kind with imaginary argument as defined by G. N. Watson in "The Theory of Bessel Functions."

* See pair No. 922 in G. A. Campbell's paper, "The Practical Application of the Fourier Integral," *Bell System Technical Journal*, 1928, vol. 7, p. 639.
† See Bibliography, (3). ‡ *Ibid.*, (4). § *Ibid.*, (5), equation (5).

the height of the conductors above the ground. The latter formula is given as a result of inserting Carson's general expression for the mutual impedance under steady-state conditions* into the Fourier integral. Peterson's solution of this integral has not been confirmed by the present investigators, and his general expression for $Z_{12}(t)$ is therefore not used in this report.

Riordan uses for the mutual impedance under steady-state conditions a formula recently given by R. M. Foster to the American Mathematical Society,† for wires unrestricted in path or length on the surface of the ground. The resultant expression for the transient induction reduces under certain conditions to equation (6). Riordan then derives expressions for the induced voltage in a communication line when the current in the power line is of the form $Ie^{j\omega t}$. The formulæ given would be extremely difficult to compute from, and, like Foster's, are not suited to engineering practice.

(3) Examination of Equation (6).

In view of the importance of equation (6) it is well at the present stage to examine the conditions under which it may be used. It, like the expression for the mutual inductance under steady conditions, is restricted theoretically to wires lying on the surface of the ground. This condition, however, while very greatly simplifying the formulæ, does not introduce appreciable error when they are applied to actual overhead lines, except when the two lines are extremely close together. End effects due to earth connections are neglected, the inducing line being assumed to be very long.

In the derivation of the expression for the generalized coefficient of mutual induction (3) the dielectric constant of the earth is assumed to be unity and therefore of negligible effect. Consequently the resultant expression for the transient mutual impedance takes no account of displacement currents in the earth. Hence it cannot be used for very small times. Under usual conditions it should always be used with some caution for times less than 1 millisecond. Actually, however, owing to the self-inductance of the circuit a finite current cannot be set up instantly in a transmission line with earth return. An approximation sufficient for practical engineering purposes may therefore be obtained if equation (6) is used to calculate the induction and consideration is given to the finite rate of build up of current in the power line. This will be further discussed later.

(4) Calculated Examples of Transient Induction.

(A) *Transient Disturbing Current of the Type $I(t) = I \sin \omega t$ (Practical Case).*

This case, that of the "splashless transient," has zero current at time $t = 0$. The difficulties which arise owing to the neglect of displacement currents when the disturbing current is assumed to have an initial finite value therefore disappear. The formulæ will give results corresponding to actual happenings throughout the period.

Equation (1) may be rewritten

$$V_{12}(t) = I(0)Z_{12}(t) + \int_0^t \frac{d}{d\tau} I(\tau) Z(t-\tau)\, d\tau \quad . \quad (7)$$

In this case,

$$I(0) = 0$$
$$I(\tau) = I \sin \omega\tau$$
$$Z(t) = \frac{1}{\pi\sigma x^2}\left(1 - e^{-\frac{\pi\sigma x^2}{t}}\right)$$

and $$Z(t-\tau) = \frac{1}{\pi\sigma x^2}\left(1 - e^{-\frac{\pi\sigma x^2}{t-\tau}}\right) \text{[from equation (6)]}$$

Inserting these values into equation (7) we obtain

$$V_{12}(t) = 0 + \frac{1}{\pi\sigma x^2}\int_0^t \frac{d}{d\tau}[I \sin \omega\tau]\left\{1 - e^{-\frac{\pi\sigma x^2}{t-\tau}}\right\} d\tau$$
$$= \frac{\omega I}{\pi\sigma x^2}\int_0^t \cos \omega\tau \left\{1 - e^{-\frac{\pi\sigma x^2}{t-\tau}}\right\} d\tau \quad . \quad . \quad . \quad (8)$$

The above formula is now in the best form for graphical integration. This is a straightforward but rather laborious proceeding, as fresh curves must be constructed for each new value of t considered. Fortunately, the results which have been obtained indicate that engineers need not determine numerical values of the induced voltage under the transient conditions.

Calculations have been made for a specific resistance of the earth equal to 4 700 ohms per cm cube, and separations of 25, 250, and 2 500 yards between the power and the communication lines. The results are shown as a series of curves in Fig. 1. These give the induced voltage on each of the communication lines during the first 0·02 sec. after the commencement of a 50-cycle earth current. The value which the induced voltage would have had, in its correct phase relation with the earth current had the latter been flowing for a considerable time, is also shown. It will be seen from the curves that the induced voltage during the transient period is always less than its corresponding steady value.

(B) *Transient Disturbing Current of the Type $I(t) = I \cos \omega t$ (Theoretically Impossible).*

This case is discussed because, although the initial conditions cannot be realized in practice, they are of interest and lead to the more practical case to be considered later.

In this case

$$I(0) = I$$
$$I(\tau) = I \cos \omega\tau$$

Despite the restrictions mentioned in part (3) of the paper, equation (6) will be used for $Z(t)$ and $Z(t-\tau)$, giving the same values as noted for example (A).

* See Bibliography, (2), equation (24), viz.

$$Z_{12}(\omega) = 2j\omega \log \frac{\rho''}{\rho'} + 4\omega\int_0^\infty [\sqrt{(\mu^2 + j)} - \mu] e^{-(h_1 + h_2)\mu|k|} \cos \mu x|k|\, d\mu$$

where $\rho'' = \sqrt{[(h_1 + h_2)^2 + x^2]}$

and $\rho' = \sqrt{[(h_1 - h_2)^2 + x^2]}$

† *Ibid.*, (6).

Inserting these values into equation (7) we obtain

$$V_{12}(t) = \frac{I}{\pi\sigma x^2}\left\{1 - e^{-\frac{\pi\sigma x^2}{t}}\right\} - \frac{\omega I}{\pi\sigma x^2}\int_0^t \sin \omega\tau \left\{1 - e^{-\frac{\pi\sigma x^2}{t-\tau}}\right\} d\tau \quad . \quad (9)$$

Calculated values of the induced voltage from equation (9) for the three lines forming the subject of example (A) are shown by the curves in Fig. 2.

It will be seen from equation (9) that at the instant

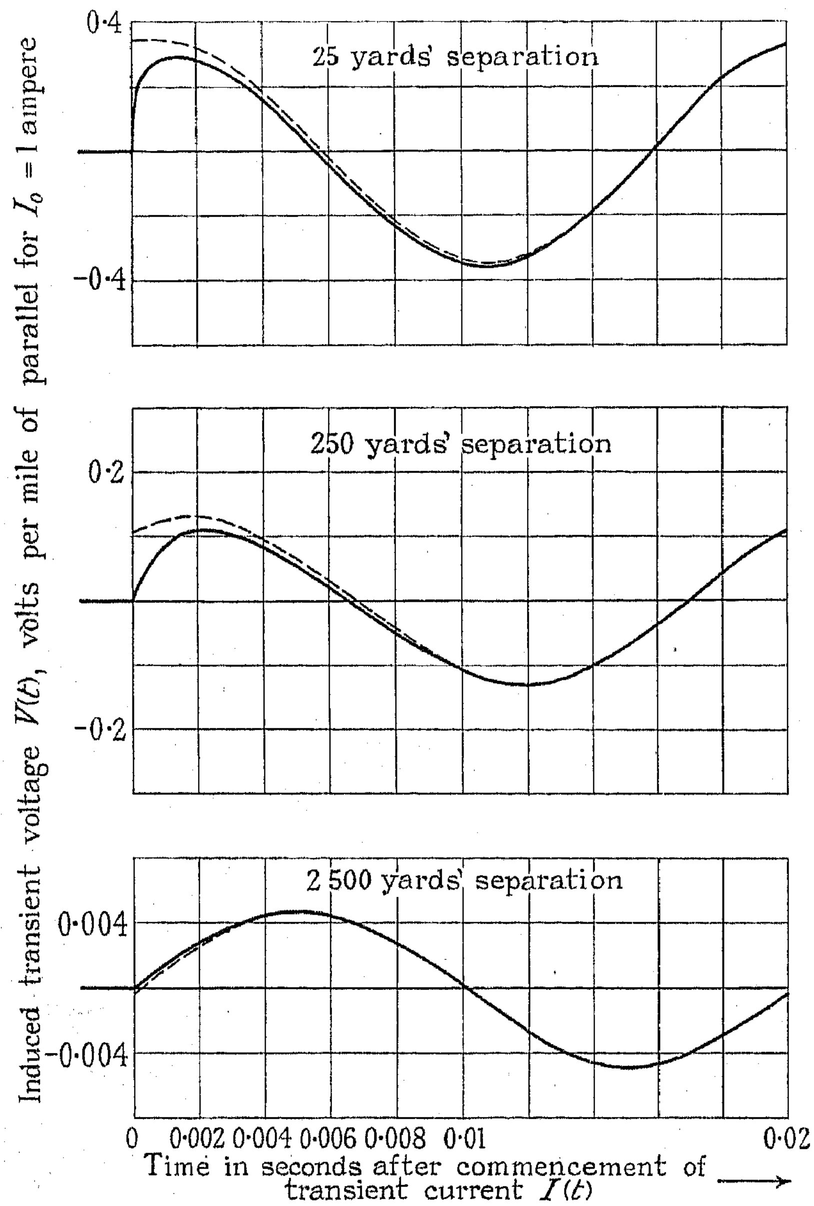

FIG. 1.—Induction between two earthed circuits under transient conditions.

$I(t) = I_0 \sin \omega t$[1].

the short-circuit current is set up in the power line ($t = 0$), the induced voltage in the parallel communication line is given by $I/(\pi\sigma x^2)$. As will be further seen from the curves in Fig. 2, this corresponds to a very high potential on the nearer lines. It amounts for the particular conditions chosen ($\rho = 4\,700$ ohms per cm cube and $f = 50$ cycles per sec.) to 130 times the maximum value of the steady sinusoidal induced voltage for the line at 25 yards' separation, and to 3·5 times the maximum value of the steady voltage at 250 yards' separation. It has already been suggested that the high value of this voltage is due to the assumption that the earth current rises instantly from zero to its maximum value. This instantaneous rise cannot take place in practice, consequently the induced voltage in the communication line will not attain values such as those indicated in Fig. 2.

(C) *Induction from a Suddenly Short-circuited Direct-current Line.*

The line is assumed to have a source of direct e.m.f. of negligible impedance connected between it and earth

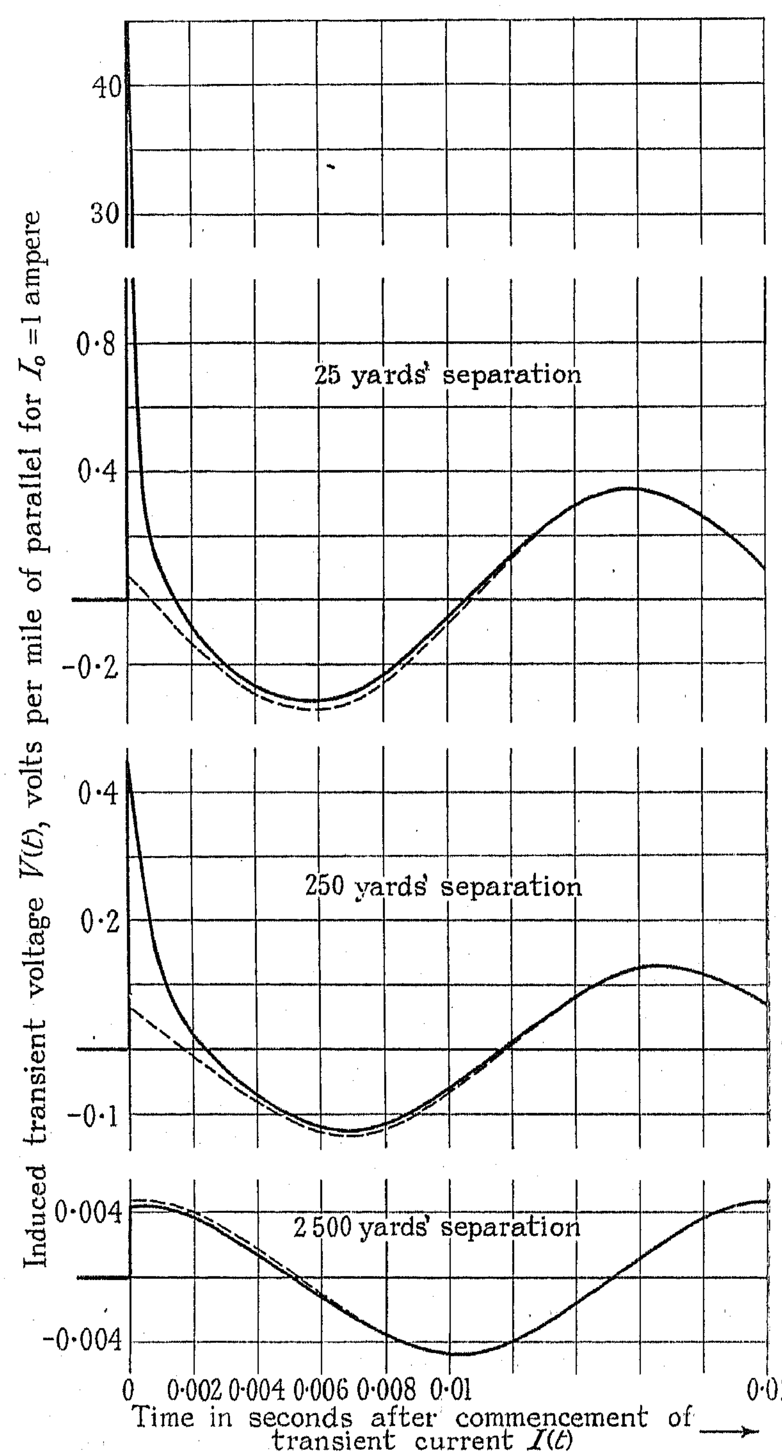

FIG. 2.—Induction between two earthed circuits under transient conditions.

$I(t) = I_0 \cos \omega t$[1].

at its near end and to be suddenly earthed at the distant end.

Under these conditions the current entering the line can be determined by the methods common to problems connected with circuit theory.

For a line of negligible leakance the entering current is given by

$$A(t) = \sqrt{\frac{C}{L}}\, e^{-\phi t}\left[I_0(\phi t) + 2\sum_{n=1}^{\infty} I_0\left\{\phi\sqrt{t^2 - \left(\frac{2nl}{v}\right)^2}\right\}\right] \quad . \quad (10)$$

where $A(t)$ is the current entering the line at time t for unit applied voltage,
$I_0(\phi t)$ is the Bessel function of the first kind with imaginary argument (ϕt) and of zero order,
$\phi = R/(2L)$,
$v = 1/\sqrt{(LC)}$, and
l is the length of the line, and R, L, and C are its primary constants per unit length.

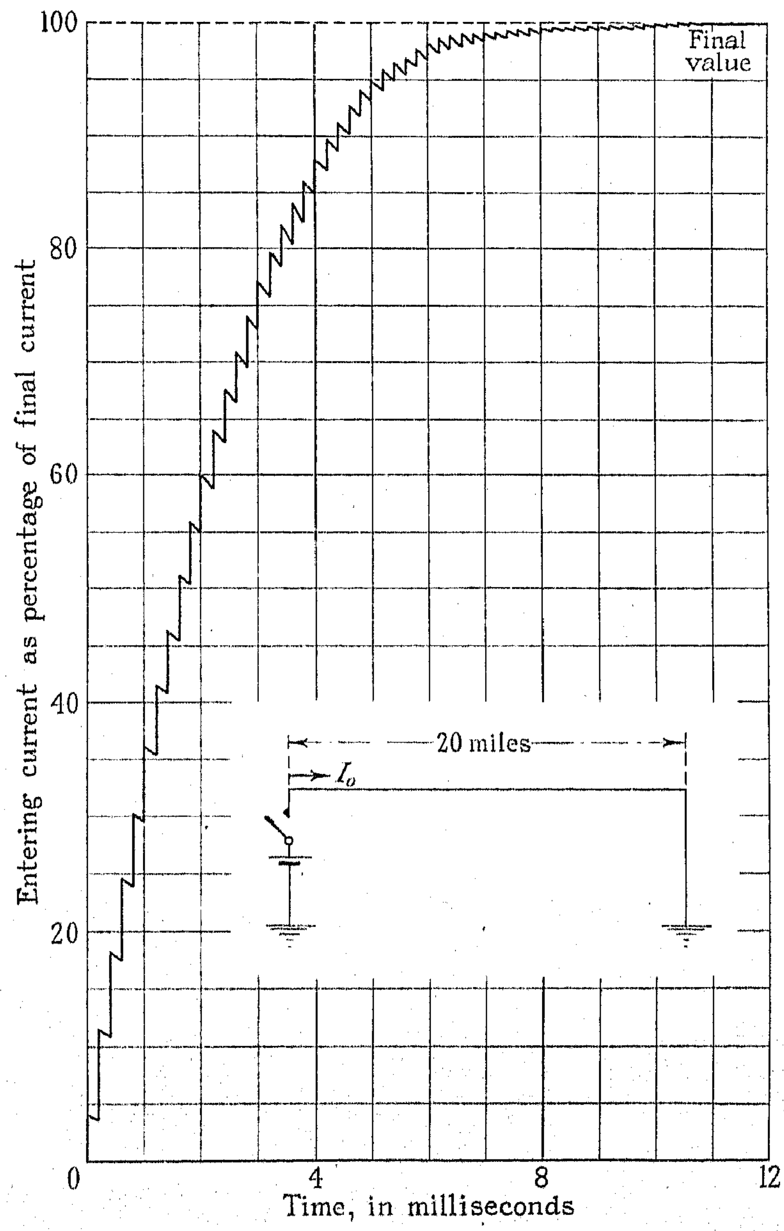

FIG. 3.—Build-up of current in an earthed transmission line.
$L = 2 \cdot 5 \times 10^{-3}$ H per mile; $C = 0 \cdot 01$ μF per mile; $R = 1$ ohm per mile.

For the purpose of calculation a transmission line having the following constants has been chosen:—
$R = 1$ ohm per mile; $L = 2 \cdot 5$ mH per mile; $C = 0 \cdot 01$ μF per mile; and a length of 20 miles between the sending end and the earth fault.

As a first approximation the impedance of the earth-return path may be considered to be included in the above figures. The entering current has been calculated for this line by the aid of equation (10) and is plotted in Fig. 3. The voltage induced in a short communication line parallel to the near end of the earthed power line can be determined by applying equation (6) to each step in the current value shown in Fig. 3 and summing the induction from all the steps which have occurred between the time under consideration and the commencement of the short-circuit. This has been done for a line at 250 yards' separation from the power line. The result is shown plotted in Fig. 4. The sudden steps in the value are due to the building-up of short-circuit current by reflections from the distant end of the line. Away from the sending end of the line the reflections will not occur exactly as shown, but a surge of potential, roughly similar to that indicated by the heavy curve in Fig. 4, will be produced. This example is of some practical interest as it corresponds to the induction caused by a rapid increase of current in the earth following a short-circuit on a direct-current railway.

(D) *Alternating-current Transmission Line with Earth Fault Occurring at Instant of Maximum Voltage (Practical Case).*

The overhead transmission line for which the calculation has been made has the same length and the line constants given for example (C). It is assumed that the line voltage is given by $\hat{E}\cos\omega t$ and that the earth fault occurs at an instant when this is a maximum. The current flowing in the earth-return circuit is given by

$$I(t) = \hat{E}A(t) + \omega\hat{E}\cos\omega t\int_0^t \sin\omega\tau A(\tau)d\tau$$
$$- \omega\hat{E}\sin\omega t\int_0^t \cos\omega\tau A(\tau)d\tau \quad . \quad (11)$$

$A(t)$ and $A(\tau)$ being obtained from equation (10).

The current flowing in the earthed line during the first $0 \cdot 02$ sec. after the fault occurs is shown in Fig. 5. The induced voltage in a parallel communication circuit can be calculated by means of equations (6) and (7) if the determination of $\frac{d}{d\tau}I(\tau)$ and the subsequent integration of

$$\int_0^t \frac{d}{d\tau}I(\tau)Z(t-\tau)d\tau$$

are performed graphically. The case of a telephone or telegraph line at 25 yards' separation from the power line has been worked out, as this separation gave the largest transient effect when examined under the artificial conditions of example (B). As in previous examples the soil resistivity was taken as 4 700 ohms per cm cube and f as 50. The result is shown on Fig. 6. It will be seen that during the first half-cycle the induced voltage rises to a value 18 per cent higher than its maximum after steady conditions have been established.

(5) CONCLUSIONS.

The conditions for which the last numerical example was worked out were chosen in order to magnify the transient distortion in the induced-voltage wave. It was seen that under these conditions there was only a slight increase in the induced voltage during the period when there can be considered to be a transient variation

in the coupling between the two circuits. From the four examples given, it can be concluded that transient variations in the coupling are of no practical importance when calculating the induction from earth-fault currents on power transmission systems. In this respect the interests of communications engineers appear to be sufficiently safeguarded when calculations are made which neglect any initial variation in the coefficient of mutual induction.

It is suggested, however, that if suitable opportunity offers, these conclusions might be confirmed by tests with an oscillograph in the field.

The authors wish to express their thanks to the Engineer-in-Chief of the Post Office and to Captain B. S. Cohen, in charge of the Research Section, for permission to publish this paper, which was originally prepared as a Research Section Report.

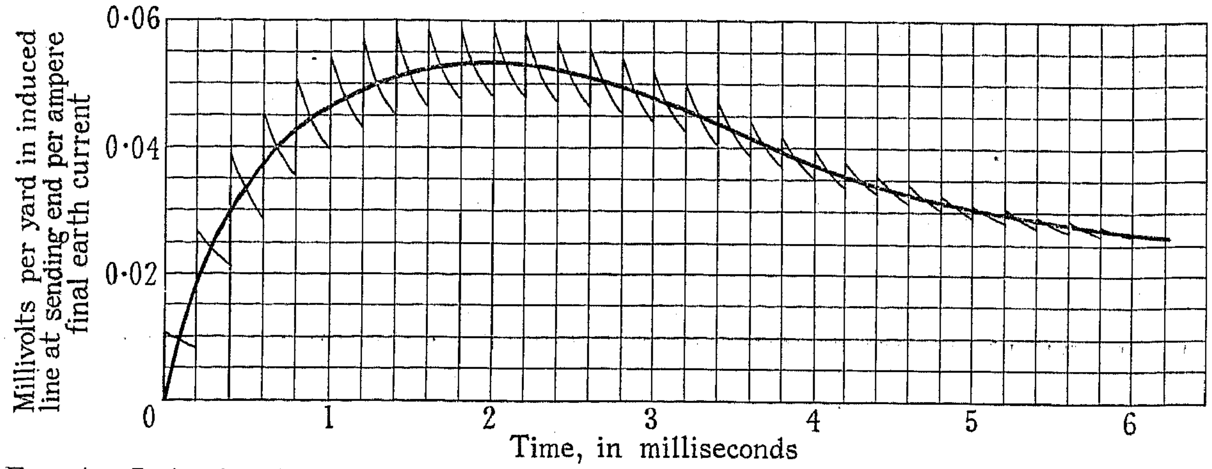

FIG. 4.—Induction from 20-mile line with build-up of earth current shown by Fig. 3.

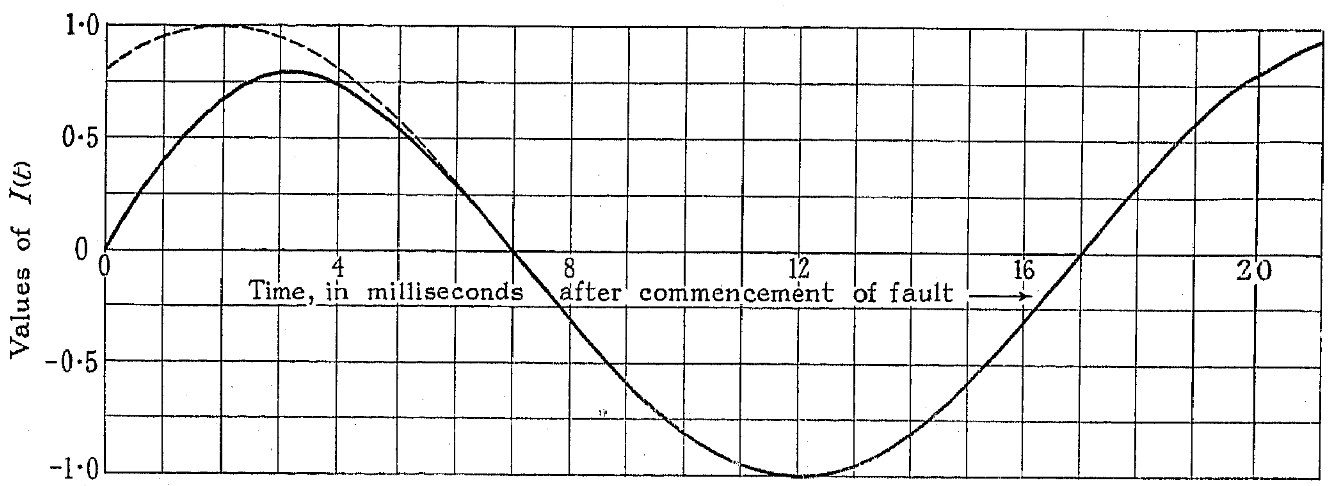

FIG. 5.—Current entering earthed transmission line with applied voltage $E \cos \omega t$.

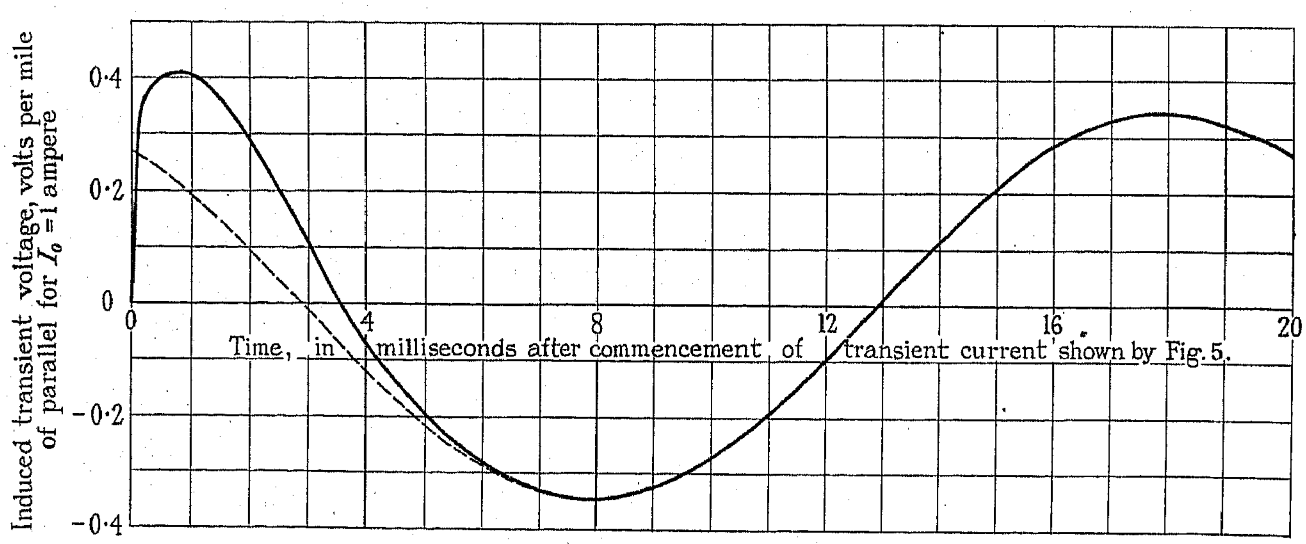

FIG. 6.—Induction from transient current in earthed transmission line. Induced line at 25 yards' separation.

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ELECTRIC AND MAGNETIC UNITS. THE BASIS OF A SYSTEM OF DEFINITIONS.*

By SIR R. T. GLAZEBROOK, K.C.B., D.Sc., F.R.S., Past-President.

(*Paper first received 5th September, and in final form 3rd October,* 1932.)

A discussion on the bases of electromagnetic theories has been in progress for some time. The following is a brief note of points raised.

At the meeting of the International Union for Physics at Brussels in 1931 a discussion took place on symbols, units, etc., in various branches of physics, and a Commission was appointed to deal with symbols, units, and nomenclature—the S.U.N. Commission—and to report to future meetings of the International Union. At the first meeting of the Commission it was decided to deal first with electrical magnitudes. A Committee of the International Electrotechnical Commission discussed the same matter at a meeting in London in September, while it was also considered by a British Association Committee of Section G.

As a result, co-operation between these three bodies was arranged and it was agreed that the S.U.N. Commission should issue to its National Committees a questionnaire and that this should also be sent to the other parties interested.

The principal issues raised by the questionnaire related to (1) the basis on which a connected account of electromagnetic phenomena should rest (should the starting point be Coulomb's law of force between magnetic poles or some other physical law?), and (2) should μ (the permeability) be treated as a quantity having dimensions in length, mass, and time, or as a pure number? In other words, are H, the strength of a magnetic field, and B, magnetic inductance, quantities having different dimensions or are they quantities of the same kind? The various national bodies were asked to send in their replies by a certain date.

A Conference between the British National Committee for Physics and others interested was held at the Royal Society on the 19th May, 1932, at which 20 representatives were present. After discussion the principles of the British reply to the questionnaire were agreed to with 3 dissentients. Stated quite briefly, the Conference accepted Coulomb's law as a starting point and was in favour of treating μ as a quantity having dimensions. A Schedule of Magnetic Measurements was drawn up as the result of the Conference. This Schedule, slightly modified, is given in Table 1.

An Electrical Congress was held in Paris during July, 1932, and it was thought desirable to take the opportunity of the presence of electricians from many nations to hold an informal Conference between representatives of the International Union of Physics and of the National Unions of a number of countries. This took place on the 9th July at the kind invitation of our French colleagues at the Maison des Polytechniciens. The informal Conference was attended by representatives from Belgium, France, Great Britain, Germany, Holland, Italy, Norway, and the United States of America. A summary was given of the replies received to the S.U.N. circular, and discussion took place on a number of propositions submitted to the Conference by the author, as President. Some of these propositions were accepted by the Conference; on others an informal vote was taken. The results of the Conference are recorded in the following statement extracted from the Minutes.

Propositions submitted to the Conference on the 9th July, 1932, by the President.

(A) *Propositions accepted by the Conference.*

(1) Any system of units recommended must retain the eight internationally recognized practical units, viz. joule, watt, coulomb, ampere, ohm, volt, farad, henry.

(2) The C.G.S. system of units is suitable for the physicist.

(3) A system of practical units, including the above eight quantities, can be derived from these by multiplying the C.G.S. unit by appropriate powers of 10.

(4) That at the request of the Conference M. Abraham should prepare, for consideration by the Commission, a preliminary Report on the Fundamental Units.

(B) *Propositions on which an Informal Vote was taken.*

(6) The system of magnetic units may be based on the following two methods as alternatives:—

(*a*) The force between two elementary magnetic poles (Coulomb).

(*b*) The force between two elements of current (Ampère).

(7) B and H are quantities of different nature.

(8) The factor $4\pi/10$ should be retained in the definition of magnetomotive force.

The Conference, it should be noted, was quite informal and was intended mainly to guide the S.U.N. Commission in the preparation of its report to the International Union of Physics at Chicago in 1933.

The Conference was entertained at lunch by our French colleagues and a very cordial vote of thanks was passed to them and in particular to Prof. Abraham and to Prof. Fabry, who had acted as interpreters.

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications, except those from abroad, should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

TABLE 1.—*Electromagnetic Units.*

Quantity designated	C.G.S. units: Symbol	Defining equation	Name	Unit	Practical units: Volt-ampere unit
Flux	Φ	$\frac{d\Phi}{dt} = -E$	Maxwell	10^8 maxwells	Volt-second
Magnetic inductance or flux density	B	$\int BdS = \Phi$	Gauss	10^8 gauss	Volt-second per cm^2
Magnetomotive force round a circuit	F	$F = 4\pi NI$	Gilbert = Oersted-cm	10^{-1} gilbert	$\frac{1}{4\pi}$ ampere-turn
Magnetizing force or field strength . .	H	$\int H \cos \epsilon ds = F = 4\pi NI$	Oersted	10^{-1} oersted	$\frac{1}{4\pi}$ ampere-turn per cm of path of H
Permeability	μ	$\mu = \frac{B}{H}$	Permeability	$\frac{10^8 \text{ gauss}}{10^{-1} \text{ oersted}}$	$\frac{\text{Volt-second per cm}^2}{1/(4\pi) \text{ ampere-turn per cm length of path of } H}$

The main discussion at the Conference dealt with the basis from which to start any system of electromagnetic units, and some further account of the questions discussed will be of interest.

Should a start be made from—

(*a*) The force between two poles (Coulomb),
(*b*) The force between two current elements (Ampère),
or
(*c*) The idea of " flux "?

There was no decided majority in favour of any one of these bases, and as a result it seemed best to explore further the possibility of treating the various suggestions as alternative methods.

ELECTROMAGNETIC UNITS.

(i) *Maxwell's system.*

$$\text{Force} = \frac{\epsilon\epsilon'}{K_0 r^2} \qquad (1)$$

$$\text{Force} = \frac{mm'}{\mu_0 r^2} \qquad (2)$$

$$\text{Force} = \frac{mi \sin \theta ds}{Ar^2} \qquad (3)$$

Whence $$\frac{A^2}{\mu_0 K_0} = (\text{velocity})^2$$

This velocity is shown by experiment to be the velocity of electromagnetic waves. Also A is constant for all media. Maxwell puts $A = 1$ and, alternatively, $K_0 = 1$ (electrostatic system), or $\mu_0 = 1$ (electromagnetic system).

(ii) *The electrodynamic system.*

In this, following Ampère, equations (2) and (3) are replaced by

$$\left.\begin{aligned} &\text{Force} = i'ds'\int\frac{[ri \sin \theta ds]}{r^3} \\ &\text{or possibly} \\ &\text{Force} = \mu_0 i'ds'\int\frac{[ri \sin \theta ds]}{r^3} \end{aligned}\right\} \qquad (4)$$

Each represents the force on an element $i'ds'$ due to a closed circuit, of which ds is an element, carrying a current i. The expression in the brackets represents a vector in a plane perpendicular to r and ds, and these vectors are to be compounded vectorially.

Denoting by Ω the solid angle subtended at the element ds' by the closed circuit, we are led to an expression which may be written

$$\int_A^B R \cos \epsilon dl = i(\Omega_B - \Omega_A) \quad \text{or} \quad \mu_0 i(\Omega_B - \Omega_A)$$

where ϵ is the angle between the direction of R and an element of length dl; hence, integrating round a complete circuit enclosing i, we obtain

$$\int R \cos \epsilon ds = 4\pi i \quad \text{or} \quad 4\pi\mu i$$

$Ri'ds'$ is the force on the element $i'ds'$.

(iii) *A system based on "magnetic flux."*

The space inside a hollow anchor ring over the surface of which is wound a single layer wire carrying a current, is found by experiments with iron filings or a magnetic needle to be in a peculiar condition and, to quote from one authority: "The magnetic disturbance at each point within the ring has not only a direction but also a magnitude. The disturbance is said to be in the form of flux." . . . "The magnetic flux can be defined as the sum total of magnetic disturbance through a cross-section perpendicular to the lines of force."

It is stated also that: "The number of ampere-turns of the exciting winding is called the magnetomotive force of the magnetic circuit, because these ampere-turns are the cause of the magnetic field."

Systems (ii) and (iii) both spring from a desire to avoid the necessity of introducing the idea of a "magnetic pole." It may be useful to carry the development of all three values further.

System (i). This is Maxwell's system, with the proviso that μ_0 and K_0 are both quantities having dimension.

In a vacuum we are to have

$$F = mm'/(\mu_0 r^2)$$

and in any other non-magnetic medium

$$F = mm'/(\mu_1 r^2)$$

when μ_1 is characteristic of the medium. In such media we have for the magnetic induction B_0 or B_1,

$$B_0 = \mu_0 H; \quad B_1 = \mu_1 H$$

where H is the strength of the magnetic field.

Hence $$B_1 = (\mu_1/\mu_0)B_0 = \mu B_0$$

where μ is the specific permeability, a non-dimensional quantity given by the ratio μ_1/μ_0. The numerical value of μ_0 is assumed to be unity.

In a magnetic medium we still have $B_1 = \mu_1 H$, but in this case μ_1 is no longer a constant. Its value is given by

$$\mu_0\left(1 + \frac{4\pi I}{\mu_0 H}\right)$$

where I is the intensity of magnetization and H the field strength measured by the force on a unit pole placed at the centre of a long narrow tunnel-shaped cylinder with its axis parallel to the lines of magnetization. It is assumed here that H and I are co-linear. If this is not the case the expression needs modification.

System (ii). In this we start from Ampère's expression for the force between a current element $i'ds'$ and a complete circuit carrying a current i.

We denote the value of this resultant force at a point P of the element $i'ds'$ by $Ri'ds'$. Let dl be an element of a curve through P making an angle ϵ with the direction of R, and let Ω be the solid angle which the circuit carrying the current i makes at P. Then it can be shown geometrically that it follows from Ampère's expression that

$$R \cos \epsilon = i\frac{d\Omega}{dl}$$

or, integrating along the curve l,

$$\int_A^B R \cos \epsilon dl = i(\Omega_B - \Omega_A)$$

Had we started as in (i) from Coulomb's law we should of course have arrived at the result

$$H \cos \epsilon = i\frac{d\Omega}{dl}$$

and from this we can identify the quantities represented by H and R in the two methods, but it seems questionable whether it is possible to identify R as magnetizing force without some reference to a magnetic pole and magnetization.

Turning now to system (iii), the ideas from which it starts seem to the author to be too vague to make it a basis from which to build. What is magnetic disturbance and how is it measured? Faraday's experiment tells us that there is something linked with a coil of wire such that, if it varies, a current is induced in the coil. If we call this quantity ϕ, then we know that $d\phi/dt = -E$, the electromotive force set up, but we are not told how to measure the e.m.f. or the current.

The object of both (ii) and (iii) is to avoid reference to permanent magnetism. An ammeter or a voltmeter depends for its effects on the forces between a current and a permanent magnet; the intelligent use of either is barred. We may measure a current by its electrolytic effects and e.m.f. by the heat generated in a coil in a calorimeter; in practice we have to connect the quantities so measured with the accepted units, the ampere and the volt, thus complicating our fundamental definitions with the value of the electrochemical equivalent of silver or, if preferred, hydrogen.

We do not know what magnetism is; it is most probably true that permanent magnetic matter does not exist, and it is certainly true that we cannot isolate a magnetic pole. It is accepted that electrical effects are due to the existence and motion of electrons. Is it more impossible to believe that magnetic effects are due to the existence and motion of dipoles, ultra-microscopic particles having opposite properties at their two ends, properties which may be due to the rotation of electrons round the axes of these particles?

The author would like to refer those who object to Coulomb's law to Appendix C of the Second Report (Newcastle 1863) of the Electrical Standards Committee. It is by Clerk Maxwell and Fleeming Jenkin and deals with the elementary relations between electrical magnitudes. Until something more satisfactory on which to base electromagnetic theories can be found, the author will continue to pin his faith to the historic method of Maxwell and the founders of the C.G.S. system.

INSTITUTION NOTES.

Ten-Year Index.

A Ten-Year Index to Volumes 60 to 69 (years 1922–1931 inclusive) of the *Journal* is in preparation and will be published in about three months' time. The published price will be 10s. 6d. per copy, but any member of the Institution can obtain a copy at the reduced price of 2s. 6d., post free, if the order form enclosed with this issue of the *Journal* is filled in and sent to the Secretary of the Institution not later than the 1st June in the case of members resident in the United Kingdom, or the 1st July in the case of members resident abroad.

Members from Overseas.

The Secretary will be obliged if members coming home from overseas will inform him of their addresses in this country, even if they do not desire a change of address recorded in the Institution register.

The object of this request is to enable the Secretary to advise such members of the various meetings, etc., of the Institution and its Local Centres, and, when occasion arises, to put them into touch with other members.

Corrections to Mr. F. M. Colebrook's Paper.

Mr. C. H. Smith has called Mr. F. M. Colebrook's attention to an error in Section 13 of the paper on "An Experimental and Analytical Investigation of Earthed Receiving Aerials" (see *Journal*, 1932, vol. 71, pp. 235–251). The wavelength scale of Fig. 13 on page 248 (i.e. variation of received power with aerial height) should read $h = \lambda/2$, $h = \lambda$, $h = 3\lambda/2$, instead of $h = \lambda/4$, $h = \lambda/2$, $h = 3\lambda/4$. This means that the available received power reaches a maximum when the aerial height is half a wavelength instead of a quarter of a wavelength as stated in the paper. Formulæ (58), (59), and (60), are quite correct, but they have been incorrectly interpreted in the sense indicated. The corresponding amendments to the last paragraph on page 247 and at the top of page 248 are obvious and need not be detailed. The same remark applies to the last paragraph but one of the summary on page 235.

Informal Meetings.

149TH INFORMAL MEETING (24TH OCTOBER, 1932).

Chairman: Prof. E. W. Marchant, D.Sc. (President).

Subject of Discussion: "The Future Prospect for Electrical Engineers" (introduced by the President).

Speakers: Messrs. A. Morgan, E. S. Byng, C. G. Osment, F. E. Rowland, G. F. Bedford, D. B. Hoseason, E. S. Ritter, W. Lang, W. E. Warrilow, E. J. Pearson, D. J. Bolton, M.Sc.(Eng.), P. P. Wheelwright, G. Pember, and J. F. Shipley.

150TH INFORMAL MEETING (7TH NOVEMBER, 1932).

Chairman: Mr. A. N. D. Kerr.

Subject of Discussion: "The Present Depression—Is Electricity the Way Out?" (introduced by Mr. J. F. Shipley).

Speakers: Messrs. A. Morgan, F. E. Rowland, W. P. Digby, A. Page, G. Davidson, The Rt. Hon. The Lord Pentland, W. E. Warrilow, J. R. Bedford, A. G. Hilling, N. Edwards, J. W. Perkins, B. Higgs, P. P. Wheelwright, W. Lang, J. H. Marsh, L. J. Gooch, and H. S. Hind.

151ST INFORMAL MEETING (21ST NOVEMBER, 1932).

Chairman: Mr. G. F. Bedford.

Subject of Discussion: "Loud-speakers" (introduced by Dr. N. W. McLachlan).

Speakers: Messrs. C. F. Phillips, F. E. Smith, W. K. Alford, L. H. Paddle, L. E. C. Hughes, Ph.D., L. D. MacGregor, G. A. V. Sowter, H. A. M. Clark, R. J. P. Jeffcock, and H. S. Hind.

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Beer, Walter William R.
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Everitt, Gilbert Norman.
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Jallings, James Harland.
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Ryan, Richard Gerald Ll.
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Shaw, Ernest Norman.
Sutton, Frederick William.
Talbot, Frederick George.
Thomas, Alan Rosser.
Thompson, Edgar Hallam.
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Tyson, William.
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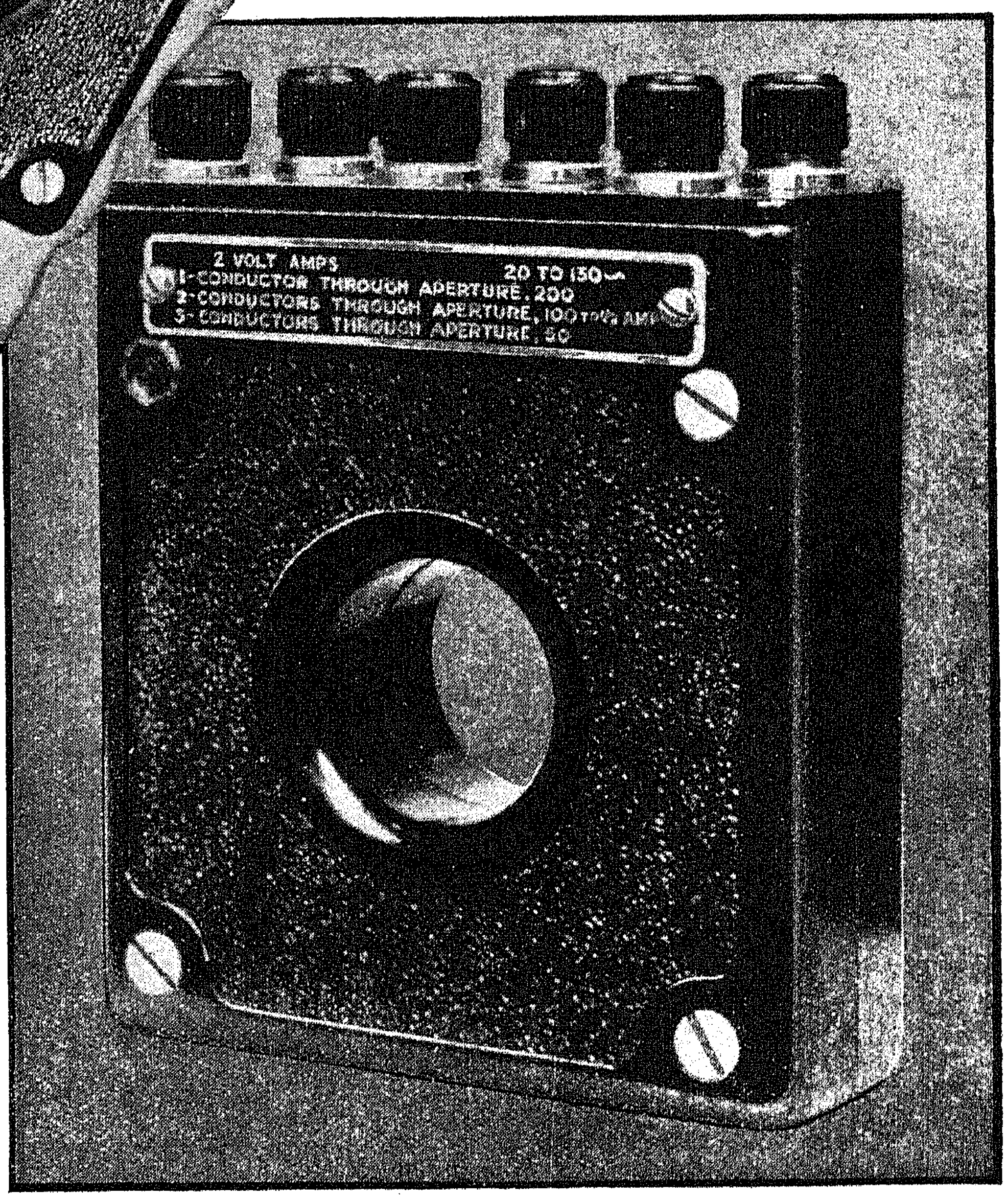

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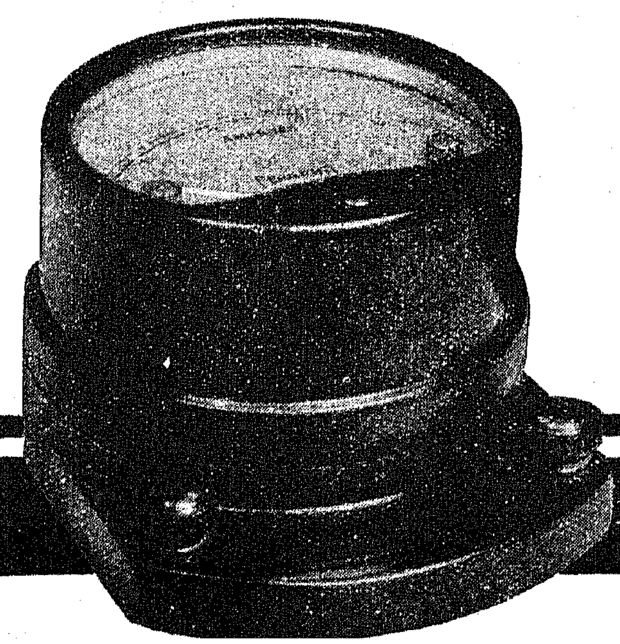

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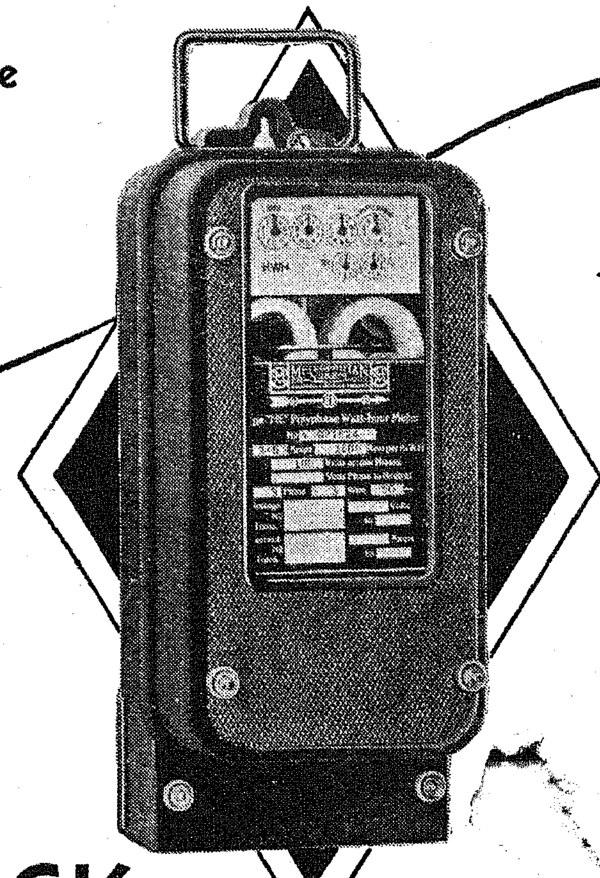

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25	1.0	"	+1.4	
100	1.0	BLUE	+1.4	+1.6
100	0.5 lag	"	0	−0.2
25	1.0	"	+1.1	

RED ELEMENT LOADED FULL VOLT x AMPS.
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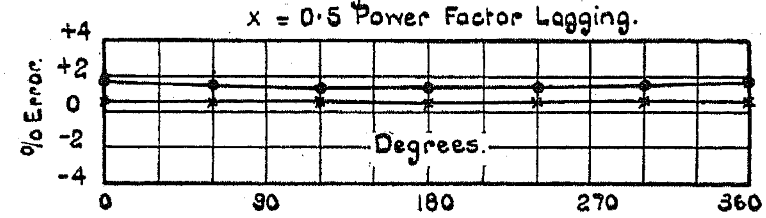
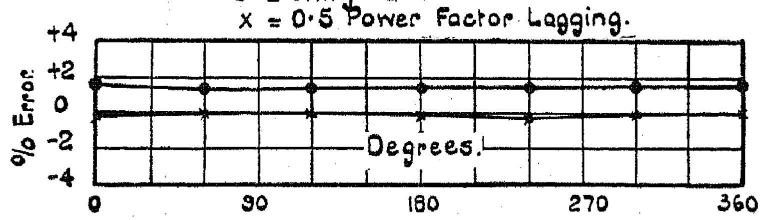
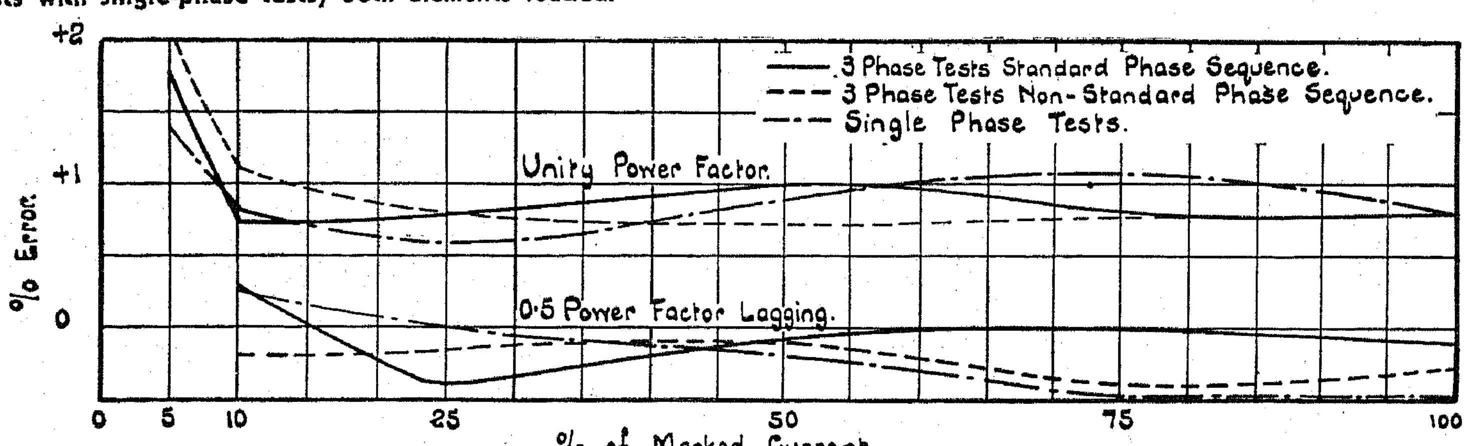


BLUE ELEMENT LOADED FULL VOLT x AMPS.
RED PRESSURE COIL EXCITED.
o = Unity Power Factor.
x = 0·5 Power Factor Lagging.



The small curves at the right represent tests carried out for comparison with curves published in "The Electrical Power Engineer" for January and February, 1927 (pp. 20 and 57). The curve below gives a comparison of 3-phase tests with single-phase tests, both elements loaded.



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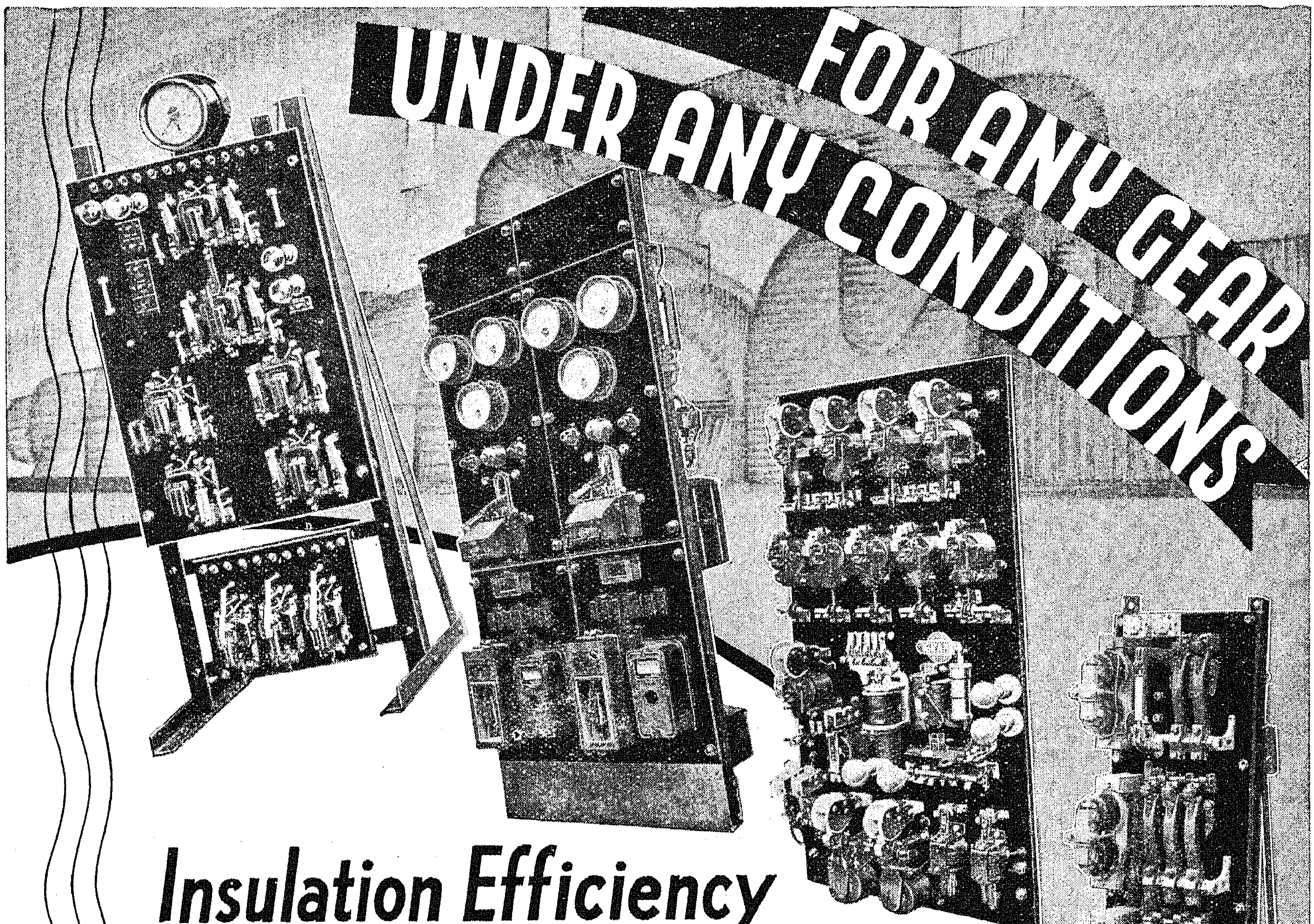
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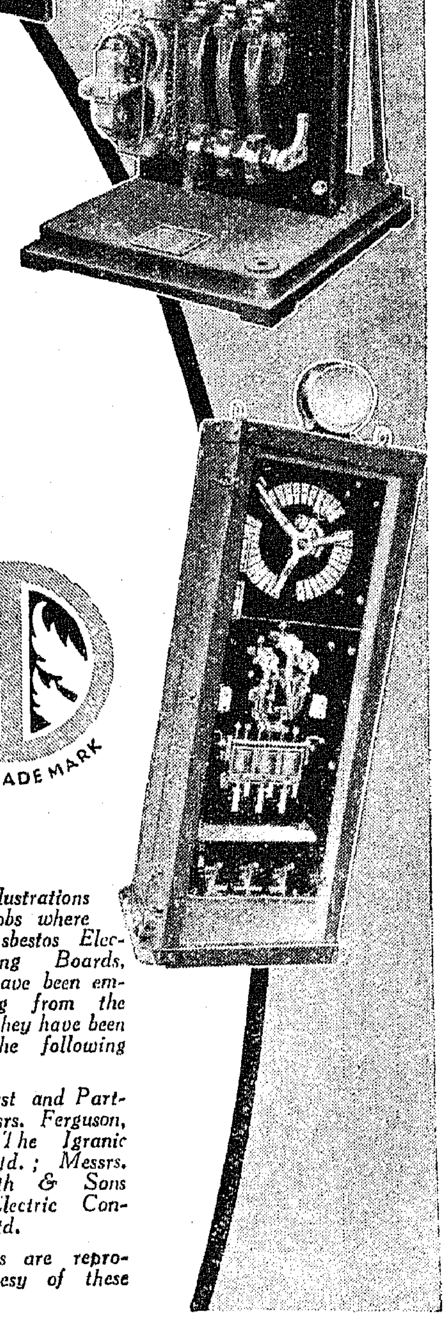

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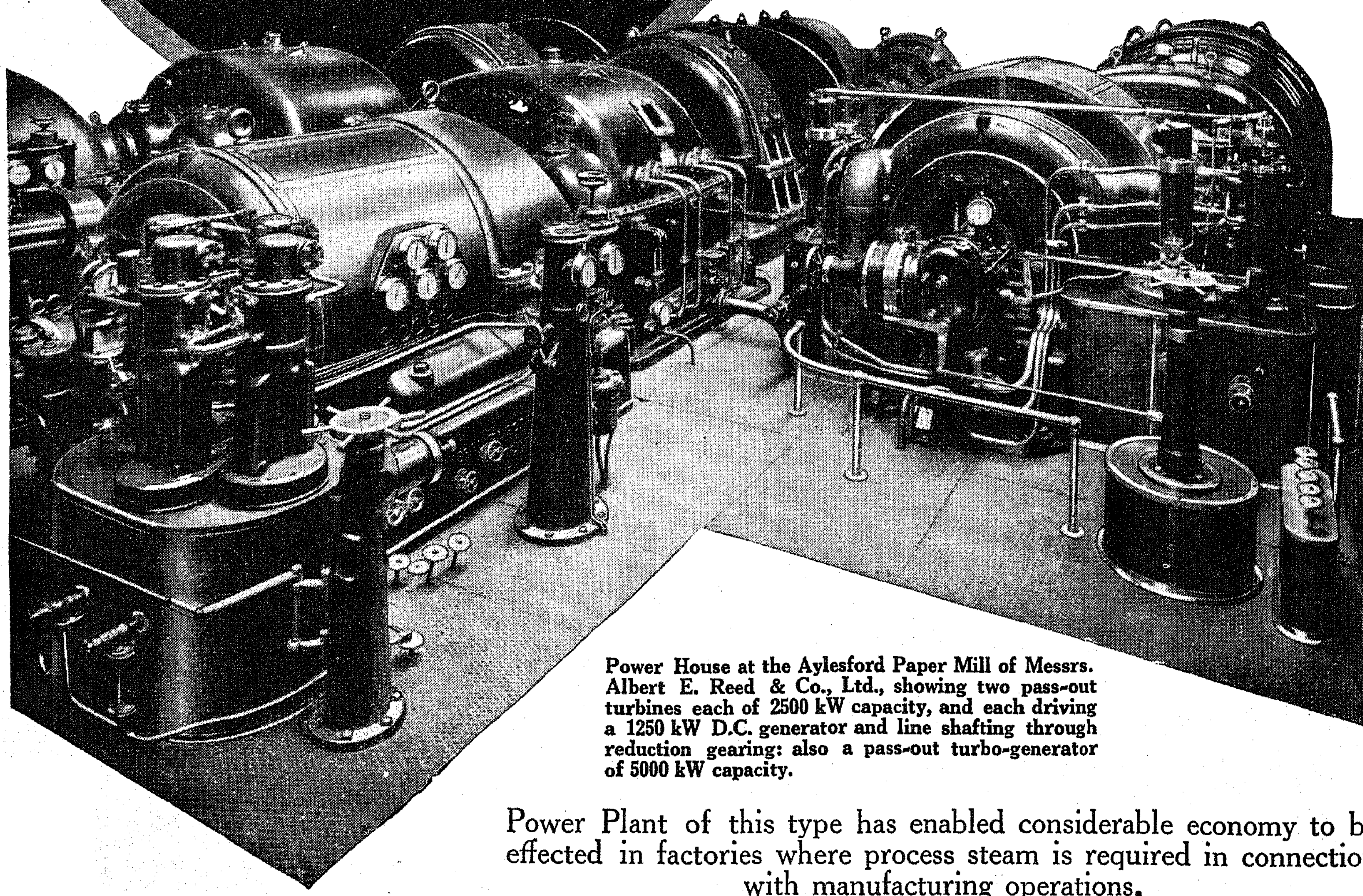

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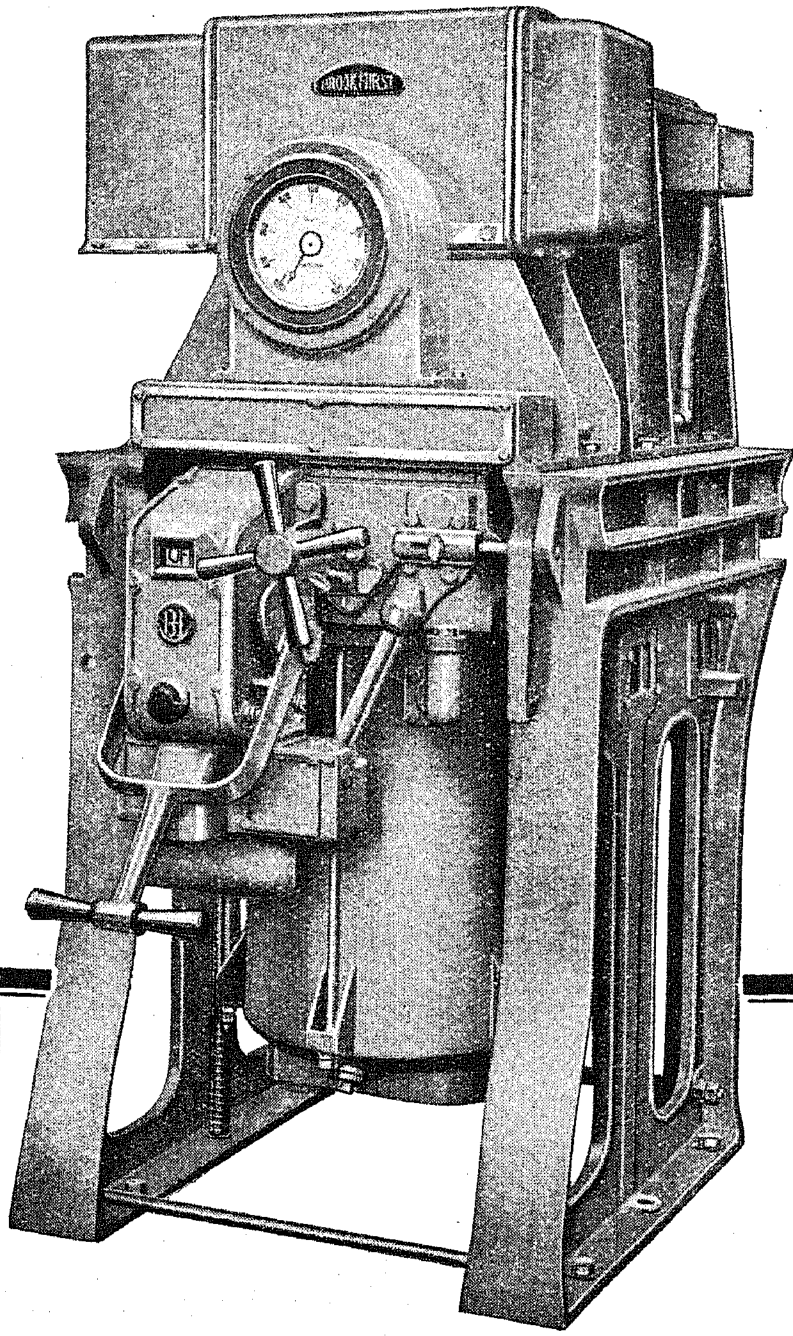

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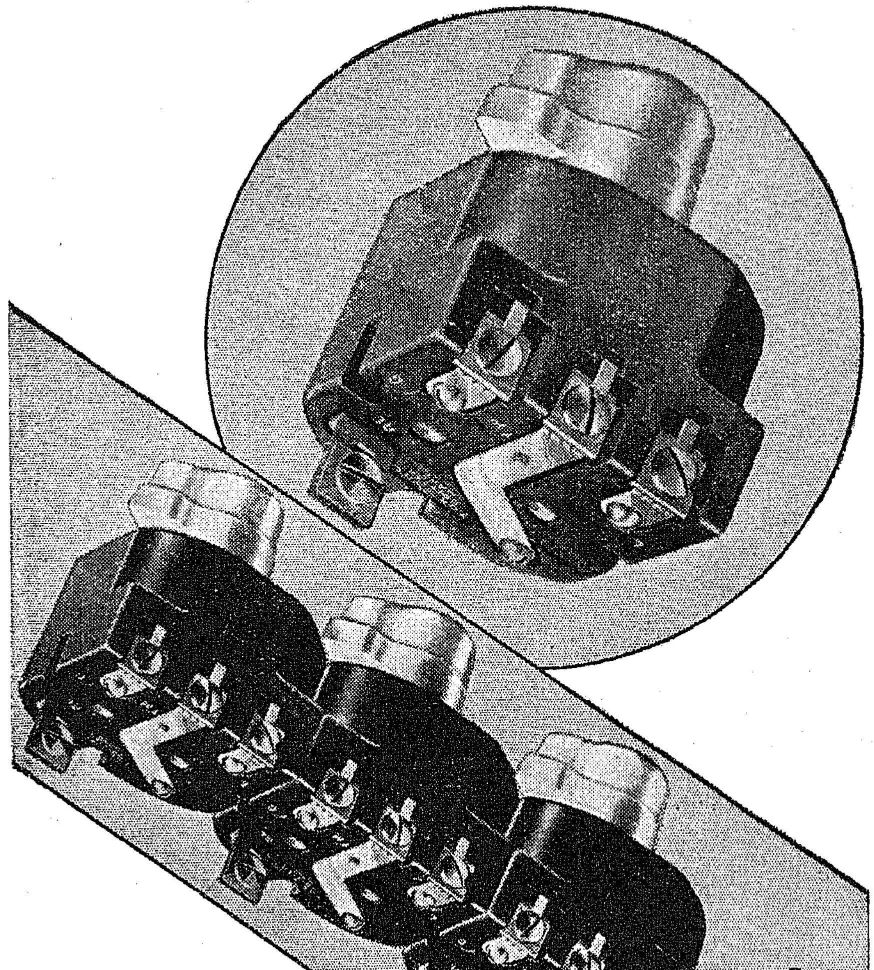

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